INDOOR AIR QUALITY RESEARCH

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
ENERGY DEVELOPMENT AND APPLICATIONS

AND THE

SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURE RESEARCH AND ENVIRONMENT

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

FIRST SESSION

AUGUST 2, 3, 1983

[No. 54]

Printed for the use of the
Committee on Science and Technology

U.S. GOVERNMENT PRINTING OFFICE
25-472 O WASHINGTON : 1984

H701-26

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INDOOR AIR QUALITY RESEARCH

TUESDAY, AUGUST 2, 1983

HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS, AND SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT,

Washington, D.C.

The subcommittees met, pursuant to call, at 9:40 a.m., in room 2318, Rayburn House Office Building, Hon. Don Fuqua (chairman of the Subcommittee on Energy Development) presiding.

Mr. SCHEUER. The subcommittee on—the joint committee of the Subcommittees on Energy Development and Applications and on Natural Resources, Agriculture Research and Environment will now come to order.

Congressman Fuqua, the chairman of the full Science Committee and the chairman of the Energy Development Applications Subcommittee, will be with us in a few minutes. In the meantime, I would like to ask unanimous consent that his opening statement be placed in the record at this point. There being no objection, so ordered.

[The prepared statement of Mr. Fuqua follows:]

OPENING STATEMENT

OF THE

HON. DON FUQUA (D-FLA)

SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS
SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT

HEARING ON
INDOOR AIR QUALITY RESEARCH: CURRENT STATUS AND FUTURE NEEDS
AUGUST 2, 1983

IT IS A PLEASURE TO WELCOME OUR WITNESSES, GUESTS AND FELLOW MEMBERS TO OUR HEARING ON INDOOR AIR QUALITY RESEARCH.

INDOOR AIR QUALITY FIRST BECAME A CONCERN FOR ENERGY POLICY WHEN RESEARCHERS FOUND THAT REDUCING AIR LEAKAGE FROM A HOUSE -- TO SAVE ENERGY -- COULD INCREASE THE CONCENTRATION OF POLLUTANTS.

SINCE MOST OF US SPEND UP TO 90 PERCENT OF OUR TIME INDOORS, THIS COULD PRESENT A SIGNIFICANT HEALTH HAZARD.

UNFORTUNATELY, OUR KNOWLEDGE OF THE SOURCES AND EFFECTS OF INDOOR POLLUTION IS STILL VERY RUDIMENTARY. AT THE BUILDING ENERGY RESEARCH WORKSHOP WHICH OUR COMMITTEE SPONSORED LAST JANUARY RESEARCHERS LISTED FIVE AREAS WHERE FURTHER WORK IS REQUIRED. THESE WERE:

-- INDOOR AIR CONTAMINANTS AND CHARACTERISTICS.

-- OBSERVED CONCENTRATIONS.

-- PERSONAL EXPOSURES TO CONTAMINANTS.

-- HEALTH EFFECTS ISSUES.

-- CONTROL OF INDOOR CONTAMINANTS.

ALL FIVE WERE LISTED AS CRITICAL TO IMPORTANT IN TERMS OF URGENCY. ALL FIVE WERE DESCRIBED AS "IN THE EARLY STAGE OF DEVELOPMENT" OR REQUIRING MUCH MORE RESEARCH.

OVER THE PAST FEW YEARS THE DEPARTMENT OF ENERGY HAS MAINTAINED A CENTER OF EXCELLENCE IN INDOOR AIR QUALITY RESEARCH AT LAWRENCE BERKELEY LABORATORY. THIS YEAR THE ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY HAS UNWISELY ATTEMPTED TO PHASE OUT MANY OF THE ACTIVITIES OF THAT CENTER. HE HAS DONE THIS IN THE FACE OF CLEAR LANGUAGE IN THE DOE AUTHORIZATION AND APPROPRIATIONS BILLS CALLING FOR CONTINUED RESEARCH IN THIS AREA. WE WILL HAVE TO LOOK INTO THE REASONS FOR THIS UNTIMELY ACTION.
BEFORE WE DO THAT, HOWEVER, WE FIRST WANT TO HEAR FROM RESEARCHERS IN THE FIELD ABOUT THE INDOOR AIR QUALITY PROBLEM AND THEIR EFFORTS TO UNDERSTAND IT BETTER. IN THAT SPIRIT, I WELCOME OUR FIRST PANEL.

Mr. **Sensenbrenner**. Mr. Chairman.

Mr. **Scheuer**. Yes.

Mr. **Sensenbrenner**. I have an opening statement that I ask unanimous consent be placed in the record at this point.

Mr. **Scheuer**. Very good. So ordered.

[The prepared statement of Mr. Sensenbrenner follows:]

OPENING STATMENT OF THE
HON. F. JAMES SENSENBRENNER, JR. (R-WIS.)

BEFORE THE JOINT EDA/NRARE SUBCOMMITTEE HEARING ON
INDOOR AIR QUALITY RESEARCH:
CURRENT STATUS AND FUTURE NEEDS

AUGUST 2, 1983

THANK YOU, MR. CHAIRMAN, FOR THIS OPPORTUNITY TO EXTEND A WELCOME TO OUR DISTINGUISHED WITNESSES.

WE LOOK FORWARD TO THEIR TESTIMONY ON EFFORTS THAT HAVE BEEN UNDERTAKEN TO UNDERSTAND THE HEALTH EFFECTS OF INDOOR AIR POLLUTION.

AS THIS COUNTRY HAS UNDERTAKEN EFFORTS TO CONSERVE OUR ENERGY CONSUMPTION, THROUGH THE REDUCTION IN ENERGY LOSS THROUGH BUILDING VENTILATION SYSTEMS, WE MUST UNDERSTAND THE CORRESPONDING EFFECT THAT THIS ACTION WILL HAVE UPON A BUILDING'S ENVIRONMENTAL QUALITY. FURTHER, AS WE STRIVE FOR INCREASES IN OUR TECHNOLOGY, THE HEALTH EFFECTS OF THESE NEW TECHNOLOGIES UPON THEIR USERS MUST BE EXAMINED. CONSERVATION EFFORTS AND TECHNOLOGICAL ADVANCES, MUST NOT BE UNDERTAKEN AT THE EXPENSE OF HUMAN HEALTH. YOUR INSIGHT ON THIS ISSUE AND ON WHAT RESEARCH REMAINS TO BE UNDERTAKEN IS APPRECIATED.

THANK YOU.

Mr. **Scheuer**. I will do the same thing with my opening statement.

[The prepared statement of Mr. Scheuer follows:]

OPENING STATEMENT, AUGUST 2, 1983, HON. JAMES H. SCHEUER

The Subcommittee on Natural Resources, Agriculture Research and Environment, and the Subcommittee on Energy Development and Applications will come to order.

Two years ago, we held hearings on the Clean Air Act, which included testimony on indoor air pollution.

One witness testified that approximately half of all lung cancer among nonsmokers comes from radon gas in homes.

Despite this and other warnings, funding for indoor air pollution research has dwindled since 1981, yet the problem has not gone away.

A 1981 National Academy of Sciences publication on "Indoor Pollutants" stated that some pollutants, primarily pesticides, found in the indoor environment, ". . . may increase cholesterol and trigyyceride concentration and so increase the risk of coronary heart disease . . ."

In order to resolve these health issues, this hearing becomes important.

Also, these hearings are timely because $2 million has been appropriated to EPA for indoor air pollution research in fiscal year 1984.

Additionally, the Natural Resources Subcommittee included a provision in the 1984 EPA authorization bill to establish a coordinated Federal research program for indoor air research.

This research program, chaired by EPA and cochaired by the Department of Energy and the Consumer Product Safety Commission, is very important to insure coordination by these agencies and to avoid a duplication of research efforts.

This and other research programs are necessary if we are to understand the nature and seriousness of the indoor air pollution problem.

Today's witnesses should provide testimony that will be beneficial to Congress as we establish guidelines for the Federal indoor air research programs.

I want to thank the witnesses for being here today and am looking forward to hearing the testimony.

[The prepared statement of Mr. McGrath follows:]

HON. RAYMOND J. MCGRATH, HEARING ON INDOOR AIR QUALITY, AUGUST 2, 1983

I want to join the Chairmen in welcoming our witnesses this morning.

I am pleased that we are holding hearings on this topic, which was not even thought of as a problem a decade ago. In my own congressional district on Long Island, New York, there have been several instances where houses have been declared uninhabitable because of indoor air pollution problems.

I look forward to the testimony of the representatives from the agencies who actually conduct research on indoor air quality here today. I think the information our witnesses provide will be quite valuable in helping the subcommittees to formulate a better definition of the public and private sector roles in this research. This in turn will assist us in formulating a streamlined and cost effective indoor air research program.

Mr. SCHEUER. We will get on with the first witness, Dr. John Spengler.

Dr. SPENGLER. Thank you.

Mr. SCHEUER. All right.

Did you have a prepared statement, Dr. Spengler?

Dr. SPENGLER. Yes, I do.

Mr. SCHEUER. OK. Your statement—and incidentally, that goes for the entire panel that will follow Dr. Spengler, all of your statements will be printed in full in the record so that when you speak you can more or less sum up your statement.

Dr. Spengler, you are sort of giving us an overview, so why don't you take 8 or 10 or 12 minutes. Then I am sure we will have some questions for you.

[The biographical sketch of Dr. Spengler follows:]

JOHN D. SPENGLER

M.S. Harvard University 1973 Environmental Health Sciences

Ph. D. State University of New York - Albany 1971 Atmospheric Sciences

B.S. University of Notre Dame 1966 Physics

Dr Spengler is an Associate Professor of Environmental Health Sciences at the Harvard School of Public Health. He has been a member of the faculty since 1973. Dr. Spengler has conducted research in the areas of personal monitoring, air pollution health effects, aerosol characterization, indoor air pollution and air pollution meteorology. He has published extensively in the open literature in each of these areas. Dr. Spengler is a member of the Air Pollution Control Association, where he serves on the Indoor Air Pollution; Biomedical Effects; and Training and Education Committees. He is also a member of the American Meteorological Society serving on the Committee on Meteorological Aspects of Air Pollution.

From 1979 through 1981, Dr. Spengler was chairman of the National Academy of Science Committee on Indoor Pollutants. He was a co-organizer of the International Symposium on Indoor Air Pollution, Health and Energy Conservation held in Amherst, Massachusetts in October 1981. He is currently an advisor to the World Health Organization on matters of Indoor Air Pollution and Personal Exposure.

STATEMENT OF JOHN D. SPENGLER, PH. D., ASSOCIATE PROFESSOR IN ENVIRONMENTAL HEALTH SCIENCES, HARVARD SCHOOL OF PUBLIC HEALTH

Dr. **Spengler**. Thank you.

I am John Spengler. I am an associate professor of environmental health at Harvard University in the school of public health.

My interests in this field of indoor air pollution go back——

Mr. **Scheuer**. Pull the microphone closer to you.

Dr. **Spengler**. Closer.

My interest in this field of indoor air pollution goes back over 8 years, where we have been involved in a long-term epidemiologic study examining the health of 10,000 adults and 10,000 children in six cities across the United States. In this process of examining the effects of outdoor air, we see some of the clearest and strongest signals for health effects coming out of indoor contaminations.

Along with the experience of being cochairman of the National Academy of Sciences Committee on Indoor Pollutants sort of giving me this kind of background and overview in this field, I think also it has been coupled—my interest has been coupled to the discovery in my own basement of 40-year-old asbestos plaster around my pipes and month-long exposures to formaldehyde due to a new rug we purchased. So, it is both personal and professional background that I come to you.

Sir, looking at our general opening remarks, there are several approaches or tacks that I could have taken. And I could have categorized the problem by reciting the litany of indoor pollutants for which there are known or suspected health effects.

Or I could have highlighted the complexity of the problem by discussing the variability in sources, the variability in locations and in ventilation rates across our housing stock and in our building. Or I could elaborate on the populations at risk, such as the elderly living in inferior housing or in mobile homes, or children exposed to parental smoke at home, or all of us exposed daily to pesticides.

But instead, I leave these kind of details to others on this panel and the panels to follow. And I will attempt to legitimize on an expanded Federal effort in the area of indoor air quality.

In June of this year, William Ruckelshaus, Administrator of the U.S. Environmental Protection Agency, addressed the National Academy of Sciences on "Science, Risk, and Public Policy." In sounding the need to strengthen the scientific basis for health- and technology-related standards, Ruckelshaus acknowledged that there are few absolutes and perhaps no measurable thresholds effects for many environmental toxins.

He pointed out that exposure information is essential component of risk assessment. He also noted that risk assessment will be an important component of revitalizing the Agency's long-term research program to develop a base for more adequate protection of public health from toxic pollutants.

If Ruckelshaus' prognosis comes true, then quantitative methods of risk assessment will be the basis for evaluating research needs, for setting standards, and for designing regulatory strategies.

In the complex area of environmental toxins, food additives, and occupational contaminants, the need to measure or calculate the multimedia dose to an individual or to a population is a vital requirement.

For many contaminants, the measure of human dose is impossible at this time, but we should strive for an improved measure of exposure. Exposure to harmful pollutants occur not just in the outdoor air, but in our homes, in our offices, in transit and in restaurants and a variety of other locations.

Pollutants for which there are national ambient air quality standards, such as carbon monoxide, nitrogen dioxide, suspended particulate matter, are having these standards exceeded in numerous indoor locations, while cleaning the outdoor air still dominates our regulatory thinking.

Improvements in outdoor air quality over the past 13 years have been substantial and beneficial. Where the pollutant is primarily an outdoor pollutant, such as sulfur dioxide from fuel combustion or ozone from photochemical smog formation, these improvements translate directly into a reduction of population exposures.

However, where unvented combustion of fuels and tobacco, volatilization of solvents, cleaners, paints and the like occur indoors, the improvements in public health, even after multibillion-dollar expenditures to control outdoor sources, are less certain.

To demonstrate this point I refer to the attached figure displaying the distribution of NO_2 concentrations indoors now obtained from a year-long measurement program conducted under our air pollution health study.

The outdoor levels in this rural town of Portage, Wis., for nitrogen dioxide were only 15 percent of our Federal standards, while the indoor average levels across all these gas cooking homes was 65 percent of our outdoor standard, and 3 percent of the homes exceeded those standards. Yet we still do not know the underlying cause for this variation in indoor concentrations. Nor do we know the distribution——

Mr. **Scheuer**. Excuse me. You said 60 percent of the homes exceeded the outdoor standards. Did you mean the indoor standards or did you mean the outdoor standards?

Dr. **Spengler**. No; if I said that, I should rephrase it. The average level inside these gas cooking homes was 65 percent of the standard, all right, indoors, all right, to be compared with the outdoor levels being 15 percent; in other words, there is a tremendous increase indoors.

Yet, given the distribution, as you see from that figure, there are some homes way out on the tail of that distribution. If this is applied to other areas across the United States where the outdoor levels are higher than this clean area of Wisconsin, the whole tail shifts over. We could expect a far greater exceedence in terms of the number of people over the standards than we currently estimate from our outdoor monitoring system.

The message is clear. If we are to quantify human exposures, we must understand our indoor environments. Perhaps an even more compelling argument for greatly accelerated federally coordinated and funded research efforts on indoor environments are the facts—the following facts.

One, that human exposure is virtually all indoors for contaminants such as formaldehyde, radon, molds, spores, fungi, aeropathogens, asbestos fibers, chlordane and other insecticides, house mites, photocopying solvents, and tobacco smoke.

And two, that new combustion sources, new building products, and new furnishings are being introduced into our homes, hospitals, schools, offices, hotels, and restaurants. They have the potential to cause irritation, sensitization, and perhaps serious health effects.

And the modern construction techniques promote building energy efficient homes and buildings. And where this means lower air infiltration, it could result in indoor air quality problems. Our knowledge of the impacts lags far behind the market buildup.

In the attached July 1, 1983, Science article, "Indoor Air Pollution: A Public Health Perspective," the current information on sources, concentrations, and health effects, research needs, and public policy implications are discussed.

In summary, Congress should give the appropriate Federal agencies—EPA, Department of Energy, HUD, Human—Health and Human Services, Consumer Products Safety Commission, Federal Trade Commission, and NIOSH—the explicit directive and appropriations to coordinate and commence a national program on indoor air quality research that contains the following components:

One, a national survey to characterize the concentrations of indoor contaminants in residences and nonindustrial workplaces. Candidate pollutants are tobacco smoke, radons, CO, NO_2, asbestos, formaldehyde, chlordane.

Irritant effects associated with indoor contaminants must be evaluated both clinically and epidemiologically.

We must strengthen our building sciences that are related to sources, ventilation, heating ventilation and air-conditioning, building materials, and bacteria and biological growth.

Four, the policy issues presented by indoor air quality need to be addressed. We need to delineate the public and private rights and responsibilities.

Five, returning to my opening remarks, our national ambient air quality standards, hazardous emission standards, and management of toxic wastes must incorporate the concepts of total human exposures to make our management of these problems effective from a cost and human health perspective.

Thank you.

[The prepared statement of Dr. Spengler follows:]

Testimony before U.S. House of Representatives' Committee on Science and Technology Joint Hearing of the Energy Development and Applications and the Natural Resources, Agriculture Research and Environment Subcommittees - on Indoor Air Quality Research: Current Status and Future Needs

Presented by John D. Spengler, Ph.D., Associate Professor, Environmental Health, Harvard University School of Public Health, Boston, Massachusetts

In June, William Ruckelshaus, Administrator for the U.S. Environmental Protection Agency, addressed the National Academy of Sciences on "Science, Risk, and Public Policy." In sounding the need to strengthen the scientific basis for health- or technology-related standards, Ruckelshaus acknowledged that there are few absolutes and perhaps no measurable threshold effects level for many environmental toxins. He pointed out that exposure information is an essential component of risk assessment. He also noted that risk assessment will be an important component of revitalizing the agency's long-term research program to develop a base for more adequate protection of the public health from toxic pollutants.

If Ruckelshaus' prognosis comes true, then quantitative methods of risk assessment will be the basis for evaluating research needs, for standard setting, and for designing regulatory stategies. In the complex areas of environmental toxins, food additives, and occupational contaminants, the need to measure or calculate the multi-media dose to an individual or to a population is a vital requirement. For many contaminants, the measure of human dose is impossible at this time, but we should strive for improved measures of exposure. Exposures to harmful pollutants occur not just in the outdoor air, but also in our homes, in offices, in transit, in restaurants, and in a variety of other locations. Pollutants which have National Ambient Air Quality Standards, such as carbon monoxide, nitrogen dioxide, and suspended particulate matter are having these standards exceeded in numerous indoor locations, while cleaning the outdoor air dominates our regulatory thinking. Improvements in outdoor air quality over the past 13 years have been substantial and beneficial. Where the pollutants are primarily from outdoor sources such as SO_2 from fuel combustion and ozone from photochemical smog formation, these improvements translate into a reduction in population exposures. However; where unvented combustion of fuels or tobacco, volatilization of solvents, cleaners, paints and the like, occur indoors, the improvements in public health after multi-billion dollar expenditures to control outdoor sources are less certain. To demonstrate this point, I refer to the attached figure displaying the distribution of indoor NO_2 concentrations obtained from a year-long measurement program conducted under our air pollution/health study. Outdoors in this rural areas of Portage, Wisconsin, the NO_2 levels were only 15% of the NAAQS, while indoors the average level across all gas-cooking homes was 65% of the outdoor standard. Three percent of the homes exceeded the standard, yet we still do not know the cause of this variation in indoor concentrations.

The message is clear--if we are to quantify human exposures, we must understand our indoor environments. Perhaps even more compelling arguments for a greatly accelerated federally-coordinated and funded research effort on indoor environments are the facts that:

1. The human exposure is virtually all indoors for contaminants such as formaldehyde, Radon, molds, spores, fungi, aeropathogens, asbestos, fibers, chlordane and other insecticides, house mites, photocopying solvents, and tobacco smoke components.

2. New combustion sources, new building products, and new furnishings are being introduced into our homes, hospitals, schools, offices, hotels, and restaurants. They have the potential to cause irritation, sensitization, and perhaps serious health effects.
3. Modern construction techniques promote building energy-efficient homes and buildings. Where this means lower air infiltration, it could result in indoor air quality problems. Our knowledge of the implications lags far behind the market build-up.

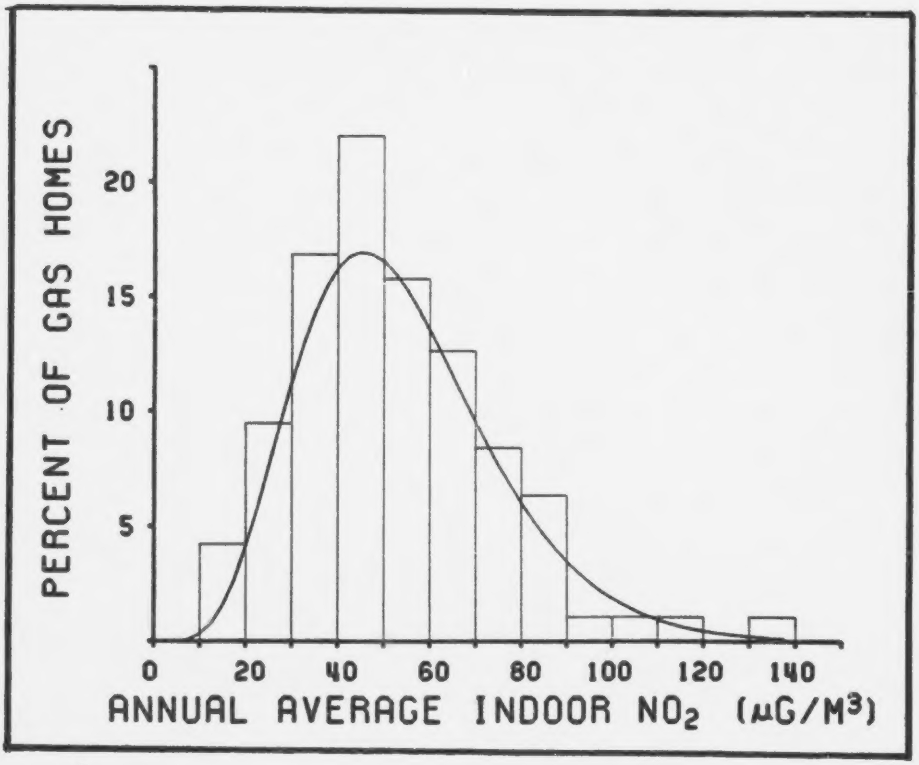
In the attached July 1, 1983, Science article, "Indoor Air Pollution: A Public Health Perspective", the current information on sources, concentrations, and health effects, research needs and public policy implications are discussed. In summary, Congress should give the appropriate federal agencies-EPA, DOE, HUD, HHS, CPSC, FTC, and NIOSH-the explicit directive and appropriations to coordinate and commence a national program on indoor air quality research that contains the following components:

1. A national survey to characterize the concentrations of indoor contaminants in residential and non-industrial work places. Candidate pollutants are tobacco smoke, Radon, CO, NO_2, asbestos, formaldehyde, chlordane.
2. Irritant effects associated with indoor contaminants must be evaluated both in clinical and epidemiologic studies.

3. Strengthening sciences related to sources, ventilation, HVAC, material damage, and biological growth.
4. The policy issues presented by indoor air quality need to be addressed. We need to delineate public and private rights and responsibilities.
5. --Returning to my opening remarks, our National Ambient Air Quality Standards, hazardous emission standards, and management of toxic wastes must incorporate the concepts of total human exposures to make our management of these problems effective from a cost and human health perspective.

John D. Spengler, August 2, 1983

Figure 1. Measured frequency distribution of indoor annual average NO_2 concentrations from 95 gas-cooking homes in rural Portage, Wisconsin (after: Spengler et al, Environ. Sci. Tech., March 1983; Sexton et al, Environ. Res., August, 1983)



1 July 1983, Volume 221, Number 4605 SCIENCE

Indoor Air Pollution: A Public Health Perspective

John D. Spengler and Ken Sexton

Summary. Although official efforts to control air pollution have traditionally focused on outdoor air, it is now apparent that elevated contaminant concentrations are common inside some private and public buildings. Concerns about potential public health problems due to indoor air pollution are based on evidence that urban residents typically spend more than 90 percent of their time indoors, concentrations of some contaminants are higher indoors than outdoors, and for some pollutants personal exposures are not characterized adequately by outdoor measurements. Among the more important indoor contaminants associated with health or irritation effects are passive tobacco smoke, radon decay products, carbon monoxide, nitrogen dioxide, formaldehyde, asbestos fibers, microorganisms, and aeroallergens. Efforts to assess health risks associated with indoor air pollution are limited by insufficient information about the number of people exposed, the pattern and severity of exposures, and the health consequences of exposures. An overall strategy should be developed to investigate indoor exposures, health effects, control options, and public policy alternatives.

Indoor air quality in nonoccupational settings has received relatively little attention from scientists, engineers, regulatory officials, and environmental groups. However, the available information suggests that elevated concentrations of some airborne contaminants are routinely encountered in indoor environments. Time-budget surveys have shown that most of us are at home more than 16 hours per day, with other indoor time divided between the workplace, commercial and public buildings, and transportation microenvironments (for instance, automobiles and subways) (*1*, *2*). Even if indoor air pollutant concentrations are low, they may make a substantial contribution to time-weighted exposures. The degree to which indoor air pollution represents a public health hazard has not been established. Nevertheless, concerns about health effects have prompted intervention at local, state, and federal levels of government to limit indoor exposures to sidestream tobacco smoke, asbestos, formaldehyde, and radon. In this article we discuss the scientific basis for recognizing indoor air pollution as a national health concern and the need for a coordinated policy to safeguard indoor air quality.

Contaminated indoor air is not new. Soot found on ceilings of prehistoric caves provides evidence of the high levels of pollution associated with inadequate ventilation of open fires. Elevated indoor pollutant concentrations continue to be a fact of life for people who live in impoverished areas and cook over open fires fueled by charcoal, wood, dung, kerosene, or oil. Exposures to gaseous and particulate pollutants for these people greatly exceed measured pollutant concentrations in urban environments (*3*).

In industrialized countries, the more obvious indoor pollution problems have been known for decades. Minimum ventilation requirements, for instance, are a standard component of building codes to control odors and combustion by-products and reduce transmission of respirable diseases. However, the complex nature of indoor nonoccupational environments in technologically advanced nations (including synthetic building materials, energy-efficient buildings, unvented heating and cooking appliances, and cleaning and personal care products) makes possible widespread indoor exposures to a broad spectrum of airborne chemicals. Although many indoor pollutants (such as radon decay products and microorganisms) are below perception thresholds, long-term exposures may cause increased rates of morbidity and mortality.

In the 10 years since Benson *et al*. (*4*) reviewed the subject, a number of reports, symposia, and articles (*5*–*12*) have been published which contain information on indoor contaminants with potentially negative health effects and on important indoor emission sources (see Table 1). Nevertheless, development of public policy to safeguard indoor air quality is hindered by a paucity of data on distributions of sources, building characteristics, daily activity patterns, indoor concentrations, exposure patterns, and health risks.

Basis for Concern

Increases in energy prices and in costs of new electricity-generating stations have encouraged individuals and institutions to seek alternative fuels and to reduce energy consumption. Because more than one-third of U.S. energy is consumed in buildings (*13*), efforts have been made to reduce energy use in the residential and commercial sectors (*14*–*16*). Common approaches include: adding insulation, reducing air-exchange rates, and fuel switching.

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increased sales of wood- and coal-burning stoves and kerosene heaters suggest a national trend away from clean space-heating fuels such as electricity and gas. Sales of wood-burning stoves in the United States increased from fewer than 200,000 in 1972 to approximately 1.5 million in 1981 (*17*). An estimated 3 million kerosene heating units were in use during the 1981–1982 winter, with projections of 8 million to 10 million by 1985 (*18*). Emissions from these heating appliances contain toxic and carcinogenic particles and gases (*19–23*), yet indoor exposures and possible health consequences have not been evaluated adequately.

Because hospitals consume approximately 15 percent of all energy used in the commercial building sector, they have been a target for energy savings (*24, 25*). However, a panel of experts who explored the opportunities and constraints associated with relaxation of Department of Health, Education, and Welfare standards concluded that "the probable limiting constraint on ventilation is control of chemical contaminants. No information exists to adequately characterize the airborne chemical load in the hospital setting at the present time" (*26*).

Reduced air-exchange rates in the presence of emissions from building materials and consumer products may adversely affect human health, welfare, and comfort. Urea formaldehyde foam insulation (UFFI), for example, has been shown to be a significant source of formaldehyde in some instances (*27–29*). Complaints, symptoms, and illnesses have been reported by occupants of buildings with UFFI, and its use has been abandoned in Canada (*27*). The Consumer Products Safety Commission recently proposed a ban on UFFI in the United States (*28*); however, this action is still subject to legislative and judicial review.

Mobile homes and prefabricated housing units are especially prone to indoor air pollution problems. They have lower mean air-exchange rates than conventional homes, are of smaller volume, use proportionally more materials containing volatile organic resins, and are more likely to use propane for cooking fuel. There were 3,722,000 occupied mobile homes in the United States during 1977 (*10*) and about 250,000 new units will be shipped this year, an increase of 15 percent over the past 2 years (*30*). Mobile homes account for about 20 percent of the new housing market, and the number of mobile home occupants is expected to increase as restrictive zoning laws are phased out by many localities and states.

Another reason for concern is the growing number of building-related illnesses that have come to the attention of public health officials. The term "sick building syndrome" refers to health symptoms (for instance, irritation of mucous membranes, headaches, dizziness, nausea, diarrhea, rashes, and abdominal and chest pain) which affect occupants of a building. The Consumer Product Safety Commission has received more than 3000 complaints to date about exposures to contaminant releases from building materials (29). The National Institute for Occupational Safety and Health (NIOSH) conducted 115 investigations between mid-1978 and 1980 based on complaints from workers in nonindustrial settings who believed they were victims of building-related pollution (*31*). The New York City Department of Environmental Protection has received many complaints about indoor air pollution, despite the fact there is no established mechanism for receiving and dealing with consumer concerns about indoor air quality (*32*). Systematic investigations of building-associated illness are beginning (*31, 33*), but local, state, and federal agencies often lack explicit authority, funds, and expertise to deal with this issue.

In summary, there is growing evidence that evaluation of indoor as well as outdoor exposures to air pollution is essential for realistic health effects assessment. If indoor exposures are not taken into account in epidemiologic investigations of air pollution, systematic and random biases may give rise to spurious conclusions (*10, 34*). Total personal exposures are often better correlated with indoor than with outdoor concentrations (*35–38*). These findings, along with concerns about reduced air-exchange rates and new indoor pollution sources, challenge the premise that costly controls on sources of ambient pollution are improving public health through reduction of human exposures.

Indoor Pollutants and Sources

Several pollutants from indoor sources affect human health. Sidestream tobacco smoke, radon and radon decay products, asbestos fibers, fiber glass, formaldehyde, combustion by-products (such as polycyclic aromatic hydrocarbons, nitrogen dioxide, carbon monoxide, hydrogen cyanide, and sulfur dioxide), aeropathogens, and allergens are associated with a range of problems from mild irritation of nasal and mucous membranes to irreversible toxic and carcinogenic effects. The available evidence of toxicity, indoor concentrations, and number of people exposed suggests that some indoor air pollutants may constitute significant public health problems. The more important pollutants identified to date are briefly reviewed below.

Combustion by-products. Indoor combustion of fuels can be a source of CO, CO_2, SO_2, formaldehyde, hydrocarbons, nitrogen oxides, and a variety of particles. Numerous studies have reported elevated indoor levels of NO_2, NO, CO, and CO_2 in homes with unvented appliances (*10*). Depending on source use and air-exchange rates, long-term indoor NO_2 averages can exceed the National Ambient Air Quality Standard (NAAQS) of 100 $\mu g/m^3$, even in areas where ambient outdoor values are 15 $\mu g/m^3$ (*34*). Peak hourly NO_2 concentrations between 200 and 700 $\mu g/m^3$ have been measured routinely in kitchens and other rooms of homes during conventional gas cooking. Elevated concentrations of NO_2 or CO have been reported for homes and schools where kerosene heaters and unvented gas heaters are used and in skating arenas with gasoline-powered ice-cleaning equipment (*28, 39*).

Exposures to NO_2 have been associated with toxicological effects including pulmonary edema, bronchoconstriction, and increased infection rates. Some epidemiologic evidence indicates that increased respiratory infection in young children and adult males and lower pulmonary function performance are associated with a history of exposure to gas stove emissions. Other studies failed to show significant effects associated with gas cooking (*40*).

Carbon monoxide from faulty furnaces and attached garages is responsible for several fatal accidents each year. Under typical use conditions, emissions from cooking appliances may raise short-term indoor CO concentrations 5 to 10 ppm. When a gas stove is used for heating, a common practice among urban poor in northern climates, concentrations of 25 to 50 ppm have been measured (*41*). Concentrations ranging from 25 to more than 100 ppm have been measured in ice-skating rinks, apartments, and offices with attached or underground garages.

Carbon monoxide forms carboxyhemoglobin (COHb) in the blood and inhibits oxygen uptake. It is not known at present whether there is a threshold for adverse effects from oxygen deprivation due to COHb. Recent work indicates that exercising adults with angina pectoris are sensitive to COHb concentrations as low as 1 percent (*42*). Community air pollution and indoor exposures to combustion by-products or sidestream cigarette smoke can raise COHb in nonsmokers to 2 to 3 percent (*43*).

National Ambient Air Quality Standards have been promulgated for CO and NO_2, and emission controls for mobile and stationary sources are required by legislative mandate. A limited number of personal exposure studies showed significant correlations between exposures and indoor concentrations. The evidence suggests that many, if not most, exposures to NO_2 and CO occur indoors and are therefore not represented accurately by outdoor monitors (*10*, *34*, *44*).

Tobacco smoke. Tobacco smoke is discussed separately for several reasons. First, nearly everyone is exposed at one time or another to tobacco smoke. Although 33 percent of the adult population regularly smoke cigarettes, this figure does not necessarily characterize the population of exposed children. For example, epidemiologic studies in the United States have shown that the percentage of children living in homes with one or more smokers ranged from 54 in Tucson to 76 for a middle-income community in St. Louis (*10*). Second, more than 2000 compounds have been identified in cigarette smoke, many of which are established carcinogens, irritants, and asphyxiants. And third, there is increasing evidence that passive exposures to tobacco smoke may affect respiratory health.

Tobacco combustion indoors contributes to concentrations of respirable particles, nicotine, polycyclic aromatic hydrocarbons, CO, acrolein, NO_2, and many other substances. The resulting concentrations vary widely, depending on the frequency and amount of smoking, air-infiltration rates, air-cleaning devices, and air-distribution systems. Measurements in bars, restaurants, airplanes (smoking section), buses, conference rooms, and offices indicate CO and particulate matter concentrations of 2 to 35 ppm and 10 to 1000 $\mu g/m^3$, respectively (*45*). Analysis of respirable particle samples collected in 80 homes over several years indicates that a "pack-a-day" smoker will contribute approximately 20 $\mu g/m^3$ to 24-hour indoor particle concentrations (*46*). Where two or more heavy smokers resided in a house with low air-exchange rates, the 24-hour NAAQS of 260 $\mu g/m^3$ was also violated.

While the health effects of smoking on smokers have been studied extensively (*47*), the health effects on nonsmokers have received far less emphasis. Many substances in cigarette smoke are irritants, and conjunctival irritation, nasal discomfort, cough, sore throat, and sneezing have been noted in nonsmokers exposed to cigarette smoke (*48*). Measured changes in heart rate, systolic blood pressure, COHb, psychomotor functions, and small airway dysfunction have also been reported in nonsmokers who are exposed to smoke (*43*, *49–51*).

Most studies of the effect of parental smoking on respiratory health in children show an association with reported respiratory morbidity in children, especially

Table 1. Summary of indoor pollutants, emission sources, and concentrations [adapted from (*10*)]. Column 3 shows typical ranges of indoor concentrations in the presence of indoor emission sources.

Pollutant	Major emission sources	Typical indoor concentrations	Indoor/outdoor concentration ratio
	Origin: predominantly outdoors		
Sulfur oxides (gases, particles)	Fuel combustion, smelters	0–15 $\mu g/m^3$	< 1
Ozone	Photochemical reactions	0–10 ppb	$\ll 1$
Pollens	Trees, grass, weeds, plants	L.V.*	< 1
Lead, manganese	Automobiles	L.V.	< 1
Calcium, chlorine, silicon, cadmium	Suspension of soils, industrial emissions	N.A.†	< 1
Organic substances	Petrochemical solvents, natural sources, vaporization of unburned fuels	N.A.	< 1
	Origin: indoors or outdoors		
Nitric oxide, nitrogen dioxide	Fuel burning	10–120 $\mu g/m^3$‡ 200–700 $\mu g/m^3$§	$\gg 1$
Carbon monoxide	Fuel burning	5–50 ppm	$\gg 1$
Carbon dioxide	Metabolic activity, combustion	2000–3000 ppm	$\gg 1$
Particles	Resuspension, condensation of vapors, combustion products	10–1000 $\mu g/m^3$	1
Water vapor	Biological activity, combustion evaporation	N.A.	> 1
Organic substances	Volatilization, combustion, paint, metabolic action, pesticides	N.A.	$\gg 1$
Spores	Fungi, molds	N.A.	> 1
	Origin: predominantly indoors		
Radon	Building construction materials (concrete, stone), water	0.01–4 pCi/liter	$\gg 1$
Formaldehyde	Particleboard, insulation, furnishings, tobacco smoke	0.01–0.5 ppm	> 1
Asbestos, mineral, and synthetic fibers	Fire retardant materials, insulation	0–1 fiber/ml	1
Organic substances	Adhesives, solvents, cooking, cosmetics	L.V.	> 1
Ammonia	Metabolic activity, cleaning products	N.A.	> 1
Polycyclic hydrocarbons, arsenic, nicotine, acrolein, and so forth	Tobacco smoke	L.V.	$\gg 1$
Mercury	Fungicides, paints, spills in dental-care facilities or labs, thermometer breakage	L.V.	> 1
Aerosols	Consumer products	N.A.	$\gg 1$
Microorganisms	People, animals, plants	L.V.	> 1
Allergens	House dust, animal dander, insect parts	L.V.	$\gg 1$

*L.V., limited and variable (limited measurements, high variation). †N.A., not applicable. ‡Annual average. §One-hour average in homes with gas stoves, during cooking.

Table 2. Control measures for indoor air pollutants.

Control measure description	Pollutant	Example
Ventilation: Dilution of indoor air with fresh outdoor air or recirculated filtered air, using mechanical or natural methods to promote localized, zonal, or general ventilation	Radon and radon progeny; combustion by-products; tobacco smoke; biological agents (particles)	Local exhaust of gas stove emissions; air-to-air heat exchangers; building ventilation codes
Source removal or substitution: Removal of indoor emission sources or substitution of less hazardous materials or products	Organic substances; asbestiform minerals; tobacco smoke	Restrictions on smoking in public places; removal of asbestos
Some modification: Reduction of emission rates through changes in design or processes; containment of emissions by barriers or sealants	Radon and radon progeny; organic substances; asbestiform minerals; combustion by-products	Plastic barriers to reduce radon levels; containment of asbestos; design of buildings without basements to avoid radon; catalytic oxidation of CO to CO_2 in kerosene burners
Air cleaning: Purification of indoor air by gas adsorbers, air filters, and electrostatic precipitators	Particulate matter; combustion by-products; biological agents (particles)	Residential air cleaners to control tobacco smoke or wood smoke; ultraviolet irradiation to decontaminate ventilation air; formaldehyde sorbant filters
Behavioral adjustment: Reduction in human exposure through modification of behavior patterns; facilitated by consumer education, product labeling, building design, warning devices, and legal liability	Organic substances; combustion by-products; tobacco smoke	Smoke-free zones; architectural design of interior space; certification of formaldehyde concentrations for home purchases

eye discomfort in the concentration range 0.1 to 0.4 ppm (*68*), while residential exposures as low as 0.02 ppm were associated with tearing and eye irritation. The fact that in-home responses occur at lower exposures may reflect a broader spectrum of sensitivity in the population at large, increased sensitivity due to prolonged low-level exposures, adaptation of volunteers in the chamber studies to elevated formaldehyde concentrations, or effects of other irritants present in indoor air. At concentrations of 10 to 100 ppm, formaldehyde exposures can cause lower respiratory irritation and pulmonary edema.

Formaldehyde effects on the nervous system are not well understood, although psychological and neurophysical effects have been reported (*10*, *70*). The results are difficult to interpret, but suggest that formaldehyde levels of ~1 ppm can affect the central nervous system. Effects include subtle changes such as short-term memory loss, increased anxiety, and slight changes in adaptation to darkness.

A variety of other organic contaminants have also been identified in indoor environments. People emit bioeffluents such as acetone, butyric acid, ethyl and methyl alcohol, and other acids and alcohols. Combustion of wood, kerosene, and tobacco produces polycyclic aromatic hydrocarbons. Application of pesticides can release chlorinated hydrocarbons or organophosphate compounds. Personal care products, cleaning materials, paints, lacquers, and varnishes generate chlorinated compounds, acetone, ammonia, toluene, and benzene. Health risks associated with indoor exposures to this diverse group of chemicals have not been investigated adequately.

Asbestos fibers. Because of the widespread use of asbestos-containing products in ceiling tiles, floor tiles, pipe insulation, spackling compounds, concrete, and acoustical and thermal insulating material, there is a large potential for public exposure (*71*, *72*). Acute exposures to asbestos and glass fibers cause severe skin irritation. A variety of neoplastic diseases, with latency periods of 15 or more years, have been associated with asbestos exposures. Increases in lung cancers, pleural and peritoneal mesotheliomas, and gastrointestinal tract cancers have been linked to occupational exposures (*73–75*). Several studies have shown increased mesothelioma rates among persons living near asbestos-production facilities and shipyards and among family members living with asbestos-exposed workers (*76–79*).

Airborne fiber concentrations determined by NIOSH standard methods range from zero during normal activities outdoors and in schools, offices, and dormitories to more than 100 fibers per milliliter during disrupting contact maintenance to ceilings (*76*, *80*, *81*). Unless the material is extremely friable, which is rare, asbestos exposures are likely to be episodic and therefore difficult to evaluate by random monitoring. Electron microscopic examination of air samples revealed values ranging from nearly zero outdoors in many U.S. cities to about 2000 ng/m^3 in a New Jersey school during custodial activities (*72*, *80*, *81*). Current asbestos standards include an Occupational Safety and Health Administration (OSHA) standard of 2 fibers per milliliter (*73*, *82*) and a recommended NIOSH limit of 0.1 fiber per milliliter (*83*).

Although few measurements of air concentrations are available, it is clear that houses, schools, and office buildings can become contaminated. Risks to the general public are unknown since only exposure-effect data from occupational settings are available. However, the possible synergism with other contaminants, particularly cigarette smoke, and the severity of the potential health consequences justify steps to limit exposure to asbestos.

Most (85 percent or more) of the asbestos in use is immobilized in strong binding material (*84*). However, if this material is deliberately or accidentally disrupted, asbestos fibers can be released. Because the material can be found in easily accessible places and in ventilation systems, there is a potential for fiber release as a result of maintenance, renovation, negligence, or vandalism. In 1978, the U.S. Environmental Protection Agency (EPA) banned spray-on application of asbestos-containing substances, except those in which the asbestos fibers are encapsulated with a bituminous or resinous binder during spraying to reduce friability after drying (*85*).

Controls

Workable and effective control strategies must be based on an understanding of several pertinent factors. First, contaminant characteristics need to be assessed, including: concentrations, reac-

[illegible], physical state, and particle size, if applicable. Second, emission source configurations should be taken into account. Are discharges continuous or intermittent, are they point or area releases, and do they originate primarily indoors or outdoors? Third, the nature of exposure response relations must be considered. Are individuals to be protected from long-term exposures to low concentrations or periodic short-term exposures to peak concentrations? Finally, the type of indoor enclosure is important. Some ameliorating measures are more suited to private residences than to public buildings, or to new, as opposed to existing, structures.

Identified indoor pollution control methods fall into five general categories: ventilation; source removal or substitution; source modification; air purification; and behavioral adjustments to reduce exposures (avoidance). These classifications are not mutually exclusive and effectual strategies might use combinations, such as ventilation, source removal, and behavioral changes to reduce nonvoluntary exposures to tobacco smoke. Table 2 summarizes the applicability of control methods to important indoor air contaminants.

Public Policy Issues

Realization that indoor air pollution may represent a public health hazard presents policy-makers with familiar questions: Is the problem serious enough to warrant official intervention and, if so, what public actions are most appropriate? Healthful indoor air quality—what it is and how to achieve it—is not yet well understood, and scientific data on exposures and associated health effects are lacking. Nevertheless, the mounting evidence of elevated indoor contaminant levels suggests that government efforts to safeguard citizens' health and safety may be justified.

Government response so far has been piecemeal and complaint-oriented. In some cases, such as asbestos, many different federal agencies have jurisdiction over portions of the problem. For other pollutants, like microorganisms, combustion by-products, and organic emissions from building materials, responsibility is not clearly defined. No overall strategy exists to provide a coordinated, well-managed approach to ensure adequate indoor air quality.

Historically, government measures to redress environmental pollution have been taken when identified pollutant hazards receive abundant attention in the media and sufficient public awareness is generated. With the possible exception of antismoking groups, no organized constituency has developed to champion the cause of clean air inside buildings. The absence of a group lobbying for healthful indoor air quality removes much of the political urgency normally associated with environmental problems. As results of ongoing research become available, it is likely that public pressure for official intervention will build and legislators will have more incentive to take action.

A more structured and institutionalized approach is advocated by many professionals involved with this issue. Suggestions have included: coordinated interagency research (*86*); consolidation of federal responsibility within one agency (*6*, *87*, *88*); amendment of the Clean Air Act (*6*, *11*); and granting of authority to states to regulate indoor air quality (*89*). A bill (HR-6323) was introduced in Congress during 1982 to appropriate funds for the Environmental Protection Agency to study the problem and recommend remedial actions.

As Sexton and Repetto (*90*) pointed out, it is essential to realize that a fundamental difference exists between indoor and outdoor air. Outdoor air is a "public good" in the sense that members of a community breathe basically the same ambient air. No rational individual would undertake the task of cleaning up the air over Boston, for example, since his or her share of the benefits would be much smaller than the costs. Nor would voluntary cooperation suffice, since those who refused to contribute could not be excluded from enjoying the benefits of reduced pollution. Similarly, in the absence of regulations or legal liability, no pollution source would spend enough on abatement, due to the difficulty of collecting from beneficiaries. The rationale for government regulation of outdoor air pollution has focused on the issue that those who suffer the effects are not compensated, nor is their interest in cleaner air readily effective in influencing polluters.

The situation is quite different for some indoor environments, especially private residences. Both the costs and benefits of pollution control are internalized within households. If occupants foul the air in their own home, they are forced to breathe it. If they attempt to improve its quality by increasing ventilation or installing air-cleaning devices, they bear the costs and enjoy the benefits. For some contaminants, such as tobacco smoke, odorants, and water vapor, benefits are readily recognizable through improvements in perceptible air quality and reduction of corrosion, soiling, and molds. For pollutants that are harmful to human health, but below perception thresholds, benefits will include reduced health risks due to lower exposures.

Creation of a regulatory framework for indoor air quality poses special policy issues which bear directly on choices about appropriate public responses (*90*). Certain aspects of nonworkplace environments are now subject to government ordinances, including residential and commercial building codes, health regulations, safety rules, and fire ordinances. However, this form of intervention is not necessarily optimal or even desirable. Although there are similarities between indoor and outdoor air, the complex set of regulations comprising the Clean Air Act should not automatically serve as a guide for indoor control strategies. Setting strict indoor air quality standards would almost certainly be expensive because of the costs associated with monitoring and regulating approximately 100 million buildings in the United States. Perhaps the most serious impediments to the regulatory approach are public antipathy toward this form of intervention and problems associated with enforcement. The diversity of nonoccupational indoor environments needs to be considered before practical and cost-effective control strategies can be designed and implemented.

It must also be taken into account that households are already making decisions about their own air quality. Promulgation of regulations might or might not improve those decisions. To determine the appropriateness of regulatory intervention it is necessary to do more than compile information about pollutant concentrations, human exposures, and associated health hazards. It is equally important to obtain information about individual perceptions of indoor air quality, public awareness of health risks, and the extent to which better information influences consumer choices. Commonsense precautions by building occupants may well prove to be the most effective and least expensive control measures. For this reason, the effectiveness of public information programs in promoting behavioral adjustments that will reduce personal exposures to air pollution needs to be evaluated (for instance, voluntary segregation of smokers and nonsmokers inside buildings).

In the development of effective public policy, the responsibilities of different sectors in society that have a stake in this issue should be emphasized. There are important distinctions between the responsibilities of individuals, building designers, contractors, operators and owners, professional organizations, product and material manufacturers, and government. Major responsibilities that should be formally recognized are summarized in Table 3.

Recommendations

The issue of indoor air pollution and its effect on public health is complex. Yet because society has been slow to recognize the importance of healthful indoor air quality, the information we have is fragmented, anecdotal, and often contradictory. As with other environmental contaminants, strategies for reducing risk to exposed populations must be based on defensible exposure-response relations. In this way, the cost-effectiveness of various control options can be evaluated on the basis of reductions in population exposures. Table 4 shows the important components of a comprehensive evaluation of indoor air pollution and summarizes our current knowledge.

Several major issues are involved in decisions concerning the need for public action to deal with indoor air pollution. First, the role of government may depend on the degree of "publicness" of a particular building. The rationale for government intervention is stronger for public buildings (such as hospitals) than private residences. Government responsibility may be different for occupational and nonoccupational settings and for existing and planned buildings.

Second, dissimilarities between indoor emission sources may be important. Many contaminants in indoor environments (tobacco smoke, combustion byproducts) result from human activities, while others (radon, formaldehyde) are less dependent on the activity patterns of occupants. Behavioral adjustment (such as prohibiting smoking in public places or using hood ventilation during cooking) may be the most effective and inexpensive way to control pollutants arising from discretionary actions. For pollutants not directly related to human activities, such as those emitted by soil, tap water, building materials, and furnishings, stricter building codes, simple air-cleaning devices, or sealants might be required.

Third, some indoor pollutants, such as tobacco smoke, are perceptible to most people, and individual actions to reduce personal exposures may be predicated on sensory stimuli. Other pollutants are

Table 3. Responsibilities for healthful indoor environments.

Individuals
Maintain and properly use products and appliances
Exercise direct discretionary control of ventilation in most residential and some occupational circumstances
Building owners or managers
Operate and maintain a balanced ventilation system in compliance with building ventilation codes
Use zone ventilation or local exhaust for indoor contaminant sources
Properly use cleaning solvents, paints, varnishes, herbicides, insecticides, furnishings, and insulation
Architects, developers, contractors
Adopt protection of indoor air quality as a design objective
Design ventilation systems to comply with new ASHRAE standard 62-1981
Provide for separation of occupants and indoor pollutant sources
Elimination or containment of potential sources
Manufacturers
Test, certify, and label products that are potential air pollution sources
Conduct research on potential health and comfort effects resulting from normal use or possible misuse of products
Substitute less harmful products and materials, if necessary
Government
Ensure healthfulness of indoor environments built, maintained, supervised, or financed through public funding
Ensure compliance with building ventilation codes and acceptable indoor air quality throughout the occupied life of a building
Sponsor research to assess indoor concentrations, health and comfort effects, control and policy options
Establish model or mandatory guidelines, codes, ordinances, or performance standards to protect the public
Provide information and assistance to state and local governments
Advise the public on safety of products, construction materials and practices, availability of monitoring equipment, and performance of HVAC systems

Table 4. Components of comprehensive evaluation of indoor air pollution and state of current knowledge.

Emission sources
Chamber studies done for several sources
Few measurements under dynamic conditions
Few studies of emission rates during normal use
Lack of information about distribution of sources within population
Dilution
Understanding of basic components affecting air-exchange rates
Measurement techniques available
Site-specific models developed, but more general application problematic
Only limited information available on distribution of air-exchange rates in existing buildings
Mixing inside buildings without mechanical ventilation systems not well understood
Indoor concentrations
Survey-type data collected for some pollutants
Applicability of survey data to entire building stock unknown
Dilution and mechanical filtration typically assumed to be first-order determinants of concentrations
Chemical and physical interactions, as well as removal rates, not well defined
Little known about variations in both removal and penetration rate
Human activity patterns
General features of population activity patterns known
Insufficient information about variations in activity patterns with age, sex, socioeconomic class, employment status, location, and season
Exposures
Relatively few studies of personal exposures to air pollution
Limited data indicate poor correlation between outdoor concentrations and personal exposures
Lack of suitable instrumentation limits application of personal exposure studies
Distribution of exposures across the population and effects of energy conservation on indoor exposures not known
Health effects
Irritant, toxic, mutagenic, and carcinogenic effects noted for many indoor contaminants
Additional information needed on central nervous system effects
Epidemiologic evidence of adverse health effects available for some pollutants
Data on dose-response relation accumulated for a few pollutants
Numbers, characteristics, and distribution of chemically sensitive individuals not known
Information lacking on health effects of long-term, integrated exposures compared to short-term, peak exposures

below perception thresholds (radon, microorganisms, asbestos, CO, NO_2, and so on). Consideration of voluntary and nonvoluntary risks is important for policy decisions. Development of simple warning devices could provide individuals with information on which to base decisions about the appropriateness of remedial measures. Such actions could reduce the need for government intervention to mitigate public health risks.

Fourth, it is necessary to specify whether building occupants are to be protected from chronic exposures to low levels of pollution or short-term peak exposures. If long-term exposures are considered important, then reductions in total human exposures to air pollution should be the goal. If short-term exposures are critical, then efforts should be focused on identifying peak concentrations and protecting the population at risk (for instance, limiting CO exposures for building occupants who use gas-cooking stoves for space heating).

Fifth, policy-makers must balance the benefits of energy conservation measures (for instance, reduced ambient pollution from fossil-fueled power plants) against the costs of deteriorating indoor air quality. Determining the essential components of healthful indoor air is a fundamental part of this process.

Sixth, if it is decided that public intervention is needed, a regulatory approach should not automatically be adopted. Policy alternatives such as economic incentives, better definition of legal rights and liabilities, public information programs, and expanded administrative efforts based on existing legislation might be more appropriate for control of indoor environmental hazards.

Because data from several studies indicate indoor exposures to some pollutants may represent significant health risks, official efforts to define the magnitude and extent of public health consequences seem justified. However, the future of public efforts to deal with indoor air pollution in nonoccupational environments is uncertain. Adequate funding is not currently available. Given the present regulatory climate of limited government intrusion and increasing reliance on free-market economics, it seems unlikely that programs focusing on indoor air pollution will be initiated in the near future. We believe that an overall strategy should be developed to ensure a coordinated, well-managed investigation of indoor air pollution exposures and their health consequences. In combination with efforts to define the problem, control options and policy alternatives should be evaluated.

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91. This work was supported in part by NIEHS grant ES-01108, EPRI grant RP-1001, and EPA grants 68-02-3201 and 2974. We thank the members of the staff and faculty at Harvard University who commented on earlier versions of this manuscript: M. J. Ellenbecker, J. S. Evans, M. W. First, R. Letz, D. W. Moeller, P. B. Ryan, S. R. Thomas, R. D. Treitman, and W. A. Turner. We are also grateful to A. Maskell who typed the article and provided editorial comments.

Cost-Effective Priorities for Cancer Prevention

Milton C. Weinstein

Summary. Faced with limited resources, the United States must set priorities for research to identify preventable causes of cancer. A quantitative approach to priority setting, based on principles of decision analysis and cost-effectiveness analysis, can offer guidance in this process. An illustrative application of such a model suggests that the National Institutes of Health–supported clinical trial of dietary β-carotene offers a greater expected reduction in cancer mortality per research dollar than carcinogen bioassays of high-volume industrial chemicals such as *p*-dichlorobenzene. National research priorities should reflect the relative cost-effectiveness of such investments.

Environmental factors are responsible for 80 to 90 percent of cancer deaths in the United States (*1, 2*). This conclusion, which once aroused considerable controversy, is now generally accepted, provided that the "environment" is broadly defined to include not only industrial chemicals and pollution, but also diet, reproductive behavior, and other elements of life-style and culture, as well as such natural phenomena as infectious agents and nonionizing radiation. Doll and Peto have placed the contribution to U.S. cancer mortality of occupational and environmental exposures to industrial chemicals at less than 5 percent, including 2 percent due to asbestos (*2*).

Growing hope during the 1970's that cancer could be controlled in large part by detecting and eliminating carcinogens has been tempered during the 1980's by the sober realization that preventing cancer will not be simple. Epidemiologic data firmly support the proposition that most cancers are preventable in principle, but current understanding leaves us far short of being able to prevent most cancer in fact. The challenge of the coming decades will be to identify the specific agents that cause or prevent cancer and, after identifying them, to develop and implement interventions to alter human exposure to them.

The problem of identifying carcinogens in the environment seems formidable enough when attention is focused on the 70,000 or so industrial chemicals in production. The cost of testing this inventory of chemicals, let alone the thousands of new chemicals entering production each year, would be huge. Even if financial cost were not a constraint, the limited supply of toxicologists and laboratories would constrain the volume of long-term bioassays.

Epidemiologic insights should, however, lead us to examine the priority-setting problem in a broader framework. If industrial chemicals other than asbestos account for 3 percent of cancer deaths, the prospect of saving 12,000 lives each year (out of 400,000 cancer deaths) should encourage us to discover the key industrial agents and control exposure to them. But if 35 percent of cancer deaths are related to diet (*2*), efforts to discover dietary factors in cancer might deserve an even greater claim on resources.

Toxicologic studies of industrial chemicals and epidemiologic studies of dietary agents are, in general, funded from different budgets, and might seem not to be in competition for the same limited resources. For the society as a whole, however, it is imperative to ask how best to spend resources in the general domain of cancer prevention. Priorities need to be set among alternative research strategies for detecting carcinogenic and anticarcinogenic agents, and such priority setting should encompass the full range of environmental factors (broadly defined) in cancer prevention.

This article illustrates a quantitative approach to priority setting, based on principles of cost-effectiveness and decision analysis. It also shows how the approach may be used to compare the cost-effectiveness of toxicologic studies of industrial chemicals and prospective trials of dietary constituents. The industrial chemical examined is *p*-dichlorobenzene, the active ingredient in mothballs. The cost-effectiveness of a randomized prospective trial of dietary β-carotene, a close relative of vitamin A, is also assessed. This comparison and other considerations lead to policy implications regarding the optimal use of resources in investigating the cancer-related effects of environmental agents.

Uncertainty is inherent in this kind of prospective analysis, and the attempt to quantitate this uncertainty may make some readers uncomfortable. However, policy decisions must and will be made in the face of uncertainty, and analysis

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Mr. SCHEUER. Thank you very much for your statement.

It seems to me that there would be a reverse correlation, looking at the abstract logic of it, and that more homes would approach the norm than outdoor air because we can control our homes individually. And those of us who are sort of attuned to the problem can take whatever measures necessary to do that.

And I am curious as to why, with the expenditure of a little effort and comparatively little dollars, where we are in control of our own lives in the place where we spend a good deal of our time, Americans haven't brought their own homes up far closer, much closer to the norm than the outside atmosphere is to the norm.

Dr. SPENGLER. Well, I could suggest a couple of reasons why this might be true.

In—I think you hit on one point. I think the solutions to a number of these problems presented by indoor air quality are well within our grasp. They are not profound. We can retrofit with air-cleaning devices or ventilate our homes better or remove the sources.

But in not all cases do we have a direct perceptive—signals that levels are high. You can't smell CO, you can't smell NO_2, you don't know what radon levels you have in your house. And so even if you could reach a solution, which you can, we don't know how to identify the variety and number of locations that have—potentially have the serious levels now. They are not easily perceived.

And that is where a lot of the effort should go, into identifying and characterizing the nature of the problem. We don't know if it is a 1-percent problem or a 20- or 30-percent problem in terms of the number of people that are affected above some level where you would suspect effects.

So just because a person can manage his home, he can do that where he can identify the pollutant. And certainly if you got particulates from cooking building up in your home, you could turn on the fan and ventilate and bring the levels down, but you cannot do that for a variety of other contaminants in which you don't have a direct signal for you, the human being, to tell you that the levels are high.

Mr. SCHEUER. In terms of income or in terms of quality of hazard, would the typical expensive house in an expensive neighborhood in town have a higher or lower level of radon and all of those other things that you mentioned?

Dr. SPENGLER. Probably to answer that you'd really have to classify by type of indoor contaminant. It's clear that radon could affect high-income housing as well as low-income housing. It crosses all barriers.

We see some things, though, disproportionate to low-income groups. We see the amount and prevalence of parental smoking highly displaced toward the low-income groups.

Mr. SCHEUER. Lead, I suppose, would be——

Dr. SPENGLER. Lead is another example. Molds and house mites and cockroaches, all which may have irritant properties because of asthma—induced asthmata—asthmatics or asthma in people, we see a clear evidence that the asthma rates in our populations are very much higher in urban areas, in urban poor, than they are in the rest of the population.

So you see by various pollutants it can shift what social classes impact it. I imagine formaldehyde is displaced to the upper income, the white-collar worker and the person who can afford new products.

Mr. **Fuqua** [presiding]. Mr. McGrath.

Mr. **McGrath**. Mr. Chairman, I ask unanimous consent to insert a statement in the record after the statement by the subcommittee chairman.

Mr. **Fuqua**. Without objection.

We will proceed now with our first panel for the testimony of Dr. Preuss?

Dr. **Preuss**. Yes.

Mr. **Fuqua**. Preuss. And Dr.——

Dr. **Moschandreas**. Moschandreas.

Mr. **Fuqua**. Moschandreas. Very good. A name like Fuqua.

Dr. **Moschandreas**. A little bit more difficult.

Mr. **Fuqua**. And James Woods.

We will start with you, Dr. Preuss.

[The biographical sketches of Dr. Preuss and Dr. Moschandreas, follow:]

BIOGRAPHY

PETER W. PREUSS, PH.D.

Associate Executive Director for Health Sciences
Consumer Product Safety Commission

As Associate Executive Director for Health Sciences, Dr. Preuss has the responsibility for implementation of the Chemical Hazards Program, the largest in the agency, whose major focus is the assessment of exposure, hazards and risks associated with chemicals in consumer products. He supervises a staff of 55, and administers a budget in excess of $3 million. Other functions include the supervision of the Health Sciences Laboratory, compliance testing of safety packaging under the Poison Prevention Packaging Act, and health support to all other Commission hazard programs.

1974 - 1979	Special Assistant to the Commissioner, and Director, Toxic Substances Program New Jersey Department of Environmental Protection
1971 - 1974	Senior Scientist, Environmental Protection Service Jerusalem, Israel
1968 - 1971	National Institute of Health Postdoctoral Fellow Hebrew University, Jerusalem, Israel Department of Organic Chemistry
1962 - 1967	Boyce-Thompson Institute for Plant Research, Yonkers, NY

Education

1967 - Ph.D.	Plant Physiology and Biochemistry, Columbia University, NY
1965 - M.A.	Plant Physiology and Biochemistry, Columbia University, NY
1962 - B.S.	Chemistry and Mathematics, Brooklyn College, NY

Professional Societies

New York Academy of Sciences
Society of Occupational and Environmental Health
American Public Health Association
American Society for Preventive Oncology
American Association for the Advancement of Science

Government Committee Affiliations

National Cancer Advisory Board
Executive Committee of the National Toxicology Program
Former Chairman, EPA Administrator's Toxic Substances Advisory Committee
White House Office of Science and Technology Policy - Cancer Policy Working Group

BIOGRAPHICAL SKETCH

DEMETRIOS J. MOSCHANDREAS is the Research Director of the Chemistry and Chemical Engineering Research Division of the IIT Research Institute. In this capacity, he directs 100 scientists and engineers involved in R&D and R&A contract research for the government, research institutes, and private industry. In the past seven years his research activities have focused on the characterization of Indoor Air Quality in residences and offices. He is currently performing chamber experiments to measure the emission rates of several indoor air pollution sources under a wide variety of conditions.

Dr. Moschandreas was the past Chairman of APCA's (Air Pollution Control Association) Committee on Indoor Air Pollution, he is the current Vice-Chairman of ASHRAE's (American Society of Heating, Refrigerating and Air Conditioning Engineers) Committee on Gaseous Pollutants. Dr. Moschandreas was a member of the National Academy of Sciences Committee on Indoor Pollutants and a member of the World Health Organization Committee on Exposures to Indoor Air Pollutants. He was Co-Chairman of the 2nd International Conference on Indoor Air Pollution and is the American Representative of the 3rd International Conference on Indoor Air and Related Concerns to be held in Stockholm, Sweden.

Dr. Moschandreas holds a Ph.D. in Atmospheric Physics, an M.S. in Mathematical Statistics, and a B.S. in Physics.

STATEMENT OF PETER W. PREUSS, PH. D., ASSOCIATE EXECUTIVE DIRECTOR FOR HEALTH SCIENCES, CONSUMER PRODUCT SAFETY COMMISSION; DEMETRIOS MOSCHANDREAS, RESEARCH DIRECTOR, CHEMISTRY AND CHEMICAL ENGINEERING, ILLINOIS INSTITUTE OF TECHNOLOGY RESEARCH INSTITUTE; AND JAMES E. WOODS, JR., PH. D., PROFESSOR, ENGINEERING RESEARCH INSTITUTE, IOWA STATE UNIVERSITY

Dr. **Preuss**. Good morning, Mr. Chairman, and members of the committee.

I am very pleased to be here today to discuss issues related to indoor air quality, and in particular the efforts of the Consumer Product Safety Commission as a part of an overall Federal program.

With your permission, sir, I will abbreviate my statement and just——

Mr. **Fuqua**. Yes; we will—without objection we will make your statement in its entirety part of the record, and if you wish to review, that will be satisfactory.

Dr. **Preuss**. Thank you.

To put the issue into perspective, I believe that it is appropriate to note some of the conclusions of the 1981 National Academy of Sciences' report on indoor pollutants, and I quote. They said:

> Many people spend large amounts of each day indoors, in many cases 80 to 90 percent. Indoor pollution in residences, public buildings and offices is created, for the most part, by the occupants' activities and their use of appliances, power equipment and chemicals, by wear and tear and outgassing of some structural or decorative materials, by thermal factors, and by the intrusion of outdoor pollutants.

In looking at how the indoor air situation may be improved, the Academy also said:

> Control strategies based on the specifications of source control are preferred, whenever feasible, because they are generally the most dependable, with respect to their extent and reliability of exposure reduction.

When this report was published by the National Academy of Sciences, a fair amount of work was already underway at a number of Federal agencies, for clearly some had already been dealing with these types of issues for a number of years.

The CPSC had been involved because most sources of indoor pollutants fall under our jurisdiction. CPSC had been involved with indoor pollutants either because the agency had been petitioned by an outside group to take action or because on its own the agency had decided that further investigation was required.

It is only during the past few years, however, that the agency has focused its attention on the quality of the indoor environment generally. In so doing, CPSC moved to commit a significant proportion of its budget and staff resources to these issues.

The Commission has consistently selected indoor air quality as a priority project, committing contract dollars and staff time to this area. The Commission has again selected indoor air quality as a priority effort for fiscal year 1984 and fiscal year 1985.

In fiscal year 1983, the Commission provided $1 million in support for indoor air quality and will provide more than $1.3 million in fiscal year 1984. Although the Commission has limited resources, we are devoting more staff time and money to indoor air quality than to any other single issue.

Today, we are looking into indoor air pollution from unvented heating and cooking appliances, such as gas stoves, kerosene heaters, gas heaters, and wood and coal burning stoves; formaldehyde offgassing from particle board and plywood; volatile organics, such as benzene, phthalates and methylene chloride from various sources in the home; asbestos fibers in the home air from the use of consumer products that contain and release asbestos, as well as from the use of asbestos as thermal insulation and in household and building materials.

Unvented gas space heaters, gas stoves, and kerosene heaters, like other unvented appliances, emit the products of combustion directly into the indoor air. Use of unvented portable heating appliances is likely to continue or even increase as consumers seek alternative heating sources in the face of rising energy costs. The possible hazard to the millions of families who use unvented fuel-fired appliances results from the byproducts produced by the burning flame.

The significance of the contribution of fuel-fired appliances to the exposure of Americans to these pollutants is dramatized by a comparison of the extent of the population exposure through indoor versus outdoor pollutant levels.

According to the President's Council on Environmental Quality in their annual report released last month, there are 23.1 million persons exposed through outdoor air to what they call unhealthful levels of nitrogen dioxide. These are levels greater than 0.26 parts per million. CEQ reported that the total national exposure was 241 million person-days to these levels, 228 million of which occurred in the southern California coastal basin.

The CPSC staff utilized the available data on consumer use of kerosene and unvented gas heaters and the mathematically modeled levels of nitrogen dioxide in homes associated with the use of these appliances to develop similar information for indoor exposure.

The staff estimates that perhaps as many as 1 to 1½ billion person-days of exposure to the unhealthy levels of nitrogen dioxide may have occurred during 1982 from consumer use of unvented heaters.

Having completed our work for the moment on kerosene heaters, I would like to bring one issue to your attention, Mr. Chairman, which I consider rather unique, and that has been our ability to actively involve the kerosene heater industry in our research.

The industry commitment of technical expertise and research dollars demonstrated a positive and constructive approach which can, I believe, be successfully applied to other source control aspects of indoor air quality.

The industry is now working on heater redesign, which should assure the adoption before the 1984–85 heating season of voluntary standards to reduce the potential of exposure to nitrogen dioxide and carbon monoxide.

We intend to apply this concept of cooperative industry, CPSC-funded research to our continuing work on unvented gas space heaters and gas stoves. We hope that cooperation with these industries and voluntary standards setting organizations will be as successful as our efforts with the kerosene heater industry.

Let me briefly mention volatile organic compounds. There is a great lack of information about the levels of volatile organics which occur in the home from a large number of consumer products, such as aerosol propellants, solvents, components of plastics, cleaners, polishes, paints, varnishes, et cetera.

To address this problem, the Commission this year undertook a study with the Oak Ridge National Laboratory to monitor residences for pollutants over a 9-month period. The number and concentrations of volatile organic compounds were generally much greater indoors than outdoors. For example, 17 substances that were present most consistently and at higher levels in the test homes were identified and quantitated. The levels of these 17 volatile organic compounds, which included benzene, toluene, ethylbenzene, xylene and others, were generally 10 times greater indoors than outdoors.

A word about asbestos. Large quantities of loosely bound asbestos material have been used in homes in a wide variety of ways. Many of these uses have left exposed asbestos that is subjected to wear and damage over the life of a home. The degree of risk to consumers from inplace asbestos remains to be established.

However, I would call to your attention the National Academy of Sciences' Committee on Indoor Air Pollution, their conclusion, which said that past home uses of asbestos may present a greater problem than asbestos in schools.

Finally, let me briefly summarize some of the areas that I see where research is necessary.

In the area of indoor pollutant exposures from fuel-fired appliances, several types of research to fully characterize exposures to find potential health effects from these exposures and develop appropriate product standards must continue.

These include laboratory emission testing to determine emission rates, field monitoring studies to determine actual exposure of people in their homes, and modeling studies to project the population exposure under a variety of conditions which affect occupied indoor spaces.

The second area is with regard to health effects. In order to better assess the potential for adverse effects, a study needs to be carried out to determine the effect of low-level and short-term peak level exposures to sulfur dioxide and nitrogen dioxide, both individually and combined in household air.

A similar study on the effects of exposure to carbon monoxide is also needed. These studies should also estimate the significance of the responses to allow for determination of the risks and the costs of such effects. More in-depth studies of the adverse effects of NO_2 on humans are also needed.

The third area is in field studies, particularly with regard to multiple pollutants, as Dr. Spengler has already mentioned. Comprehensive exposure data and consumer use information are necessary to relate and compare various indoor sources of combustion pollutants, as well as volatile organics and other chemicals released into the indoor air from the use of consumer products.

A major field study should be considered, which would include monitoring year round in homes where combustion appliances or other pollutant sources of interest are used; consumer use surveys to document the presence and normal pattern of use of these products; as well as appliances and building materials which may be sources of indoor air pollutants; as well as health effects surveys of homes with and without combustion appliances to evaluate the effects of exposure to pollutants from these appliances.

To conclude, I would like to say a word about interagency coordination.

A coordinated program of indoor air quality research is clearly needed. Coordinated research planning would be enhanced through a mechanism such as the Federal Committee on Indoor Air Quality that was suggested by this committee.

CPSC has often expressed its concern and committed significant resources to efforts to assure the quality of indoor air. The Consumer Product Safety Commission is committed to taking the necessary actions to assure that the many consumer products under our jurisdiction do not endanger the public health through pollutant emissions into the indoor air.

We are a small agency, however, and the research needs that I have outlined today are clearly beyond our capabilities. However, through a coordinated effort between and among a number of agencies, such as CPSC, EPA, the Department of Energy, the Department of Health and Human Services and others, I think we can develop the exposure and health effects data necessary for good public policy decisionmaking on this matter.

Mr. Chairman, I have brought with me excerpts from staff documents which provide more detailed data on the findings of our indoor air quality research. I would like to submit them for the record and would be glad to answer any questions.

[The prepared statement of Dr. Preuss follows:]

STATEMENT OF

PETER W. PREUSS, PH. D.
ASSOCIATE EXECUTIVE DIRECTOR FOR HEALTH SCIENCES
U.S. CONSUMER PRODUCT SAFETY COMMISSION

BEFORE THE

SUBCOMMITTEE ON ENERGY DEVELOPMENT
AND APPLICATIONS

SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURE RESEARCH AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

AUGUST 2, 1983

SUMMARY

The Commission has been active in indoor air quality research for many years because many of the sources of indoor pollution are products under our jurisdiction. Previous efforts addressed asbestos, benzene, vinyl chloride, n-hexane, and aerosol solvents and propellants.

It is important that energy conservation and indoor air quality be discussed together. The alternative heating devices - kerosene heaters, unvented gas space heaters, and coal and wood burning stoves - have dramatically expanded in use as consumers seek more economical sources of heat. The potential hazards presented by exposure to the combustion products - carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, formaldehyde and particulates - introduced into the home by these devices is the subject of our current research.

The significance of the contribution of fuel-fired appliances to the exposure of Americans to hazardous pollutants is dramatized by a comparison of the extent of the population exposure through indoor versus outdoor pollutant levels. According to the President's Council on Environmental Quality (CEQ) Annual report released in June 1983, 23.1 million persons were exposed through outdoor air to "unhealthful" nitrogen dioxide levels (above 0.26 ppm) in 1981. CEQ reported that the total national exposure was 241 million person days, 228 million of which occurred in the southern California coastal basin (Los Angeles area). CEQ reports that the people exposed to "unhealthy" outdoor levels outside of southern California were only exposed, on the average, two days during the year.

The Consumer Product Safety Commission's staff utilized the available data on consumer use of kerosene and unvented gas heaters and the levels of nitrogen dioxide in homes associated with use of these appliances to develop similar information for indoor exposure. The staff estimates that about one billion to one and one-half billion person days of exposure to "unhealthy" levels of nitrogen dioxide occurred during 1982 from consumer use of unvented gas heaters and kerosene heaters. More significantly, American consumers were exposed to these levels in areas of "clean" outdoor air, and the exposures were likely to have occurred on 90 to 120 days and to have lasted from 6 to 10 hours each day.

Energy conservation has had more of'an effect on indoor air quality than the introduction of new products into the home. The "tightening" of homes and use of new insulations and new building products has contributed to other problems. The Commission research in this area has involved off-gassing of formaldehyde from urea-formaldehyde foam insulation, pressed wood and other products, as well as a study to identify and evaluate the toxicological significance of the volatile organics found in residential air.

The Commission has consistently selected indoor air quality as a priority project, committing contract dollars and significant staff resources to research in these areas. The Commission has again selected indoor air quality as a priority effort in FY 1984 and FY 1985. In FY 1983 the Commission provided a million dollars in funding for indoor air quality and in FY 1984 will provide more than a 1.3 million dollars in funding to this effort. Although the Commission has limited resources we are devoting more staff time and money to indoor air quality than to any other issue.

We have over the past several years coordinated our work with the other agencies and interested groups. There is a definite need for further research on indoor air quality - research that is well beyond the capabilities of CPSC alone. A mechanism for coordinating and promoting research directed at enhancing our understanding of the indoor air environment is needed.

The structure for coordination developed by this Committee, that of a federal Committee co-chaired by CPSC, working with an advisory group of representatives of industry, the scientific community, public interest organizations and state and local governments could assist in assuring the cooperative development of the research program and the coordinated use of the research information.

MR. CHAIRMAN, AND MEMBERS OF THE COMMITTEE, I AM VERY PLEASED TO BE HERE TODAY TO DISCUSS ISSUES RELATED TO INDOOR AIR QUALITY, AND IN PARTICULAR, THE EFFORTS OF THE CONSUMER PRODUCT SAFETY COMMISSION (CPSC) AS A PART OF AN OVERALL FEDERAL PROGRAM.

TO PUT THE ISSUE INTO PERSPECTIVE, I BELIEVE THAT IT IS APPROPRIATE TO NOTE SOME OF THE CONCLUSIONS OF THE 1981 NATIONAL ACADEMY OF SCIENCES' REPORT ON INDOOR POLLUTANTS:

> "MANY PEOPLE SPEND LARGE AMOUNTS OF EACH DAY INDOORS - IN MANY CASES, 80-90 PERCENT."
>
> "INDOOR POLLUTION IN RESIDENCES, PUBLIC BUILDINGS, AND OFFICES IS CREATED FOR THE MOST PART BY THE OCCUPANTS' ACTIVITIES AND THEIR USE OF APPLIANCES, POWER EQUIPMENT, AND CHEMICALS, BY WEAR AND TEAR AND OUTGASSING OF SOME STRUCTURAL OR DECORATIVE MATERIALS, BY THERMAL FACTORS, AND BY THE INTRUSION OF OUTDOOR POLLUTANTS."
>
> "INDOOR AIR POLLUTANTS GENERATED OR RELEASED INDOORS TYPICALLY OCCUR IN CONCENTRATIONS AND MIXTURE THAT ARE OFTEN EPISODIC AND GENERALLY VARY OVER A WIDE RANGE OF TIMES AND FROM ONE SPACE TO ANOTHER. AS A RESULT HUMAN EXPOSURES ARE DIFFICULT TO ASSESS FOR INDIVIDUALS OR GROUPS. IF, IN ADDITION, THE ADVERSE HEALTH EFFECTS ARE SUBTLE, AND ESPECIALLY IF THEY ARE DELAYED, ASSOCIATIONS BETWEEN INDOOR AIR POLLUTANTS AND DISEASE OR PREMATURE MORTALITY ARE UNLIKELY TO BE DISCOVERED OR DEMONSTRATED WITHOUT A SPECIFIC AND SUBSTANTIAL EFFORT."

IN DISCUSSING THE HEALTH EFFECTS OF INDOOR POLLUTANTS THE NATIONAL ACADEMY OF SCIENCES' COMMITTEE CONCLUDED THAT:

> "IN EVALUATING HEALTH RISKS, IT IS REASONABLE TO COMPARE INDOOR EXPOSURE WITH AMBIENT-AIR-QUALITY STANDARDS FOR POLLUTANTS

FOR WHICH THERE ARE SUCH STANDARDS."

AND, FINALLY, IN LOOKING AT HOW THE INDOOR AIR SITUATION MAY BE IMPROVED, THE ACADEMY SAID:

> "WE CONCLUDE THAT THE BEST APPROACH TO THE REDUCTION OF HEALTH DAMAGE FROM EXPOSURE TO INDOOR CONTAMINANTS IS TO REDUCE THE POPULATION EXPOSURE TO THOSE CONTAMINANTS. CONTROL STRATEGIES FOR SOME POLLUTANTS WOULD TARGET THE HIGH-EXPOSURE GROUPS. FOR OTHER POLLUTANTS, LOWERING THE POPULATION-WEIGHTED MEAN EXPOSURE WOULD, BY BEST ESTIMATES, REDUCE THE HEALTH HAZARDS."
>
> "CONTROL STRATEGIES BASED ON THE SPECIFICATIONS OF SOURCE CONTROL ARE PREFERRED, WHENEVER FEASIBLE, BECAUSE THEY ARE GENERALLY THE MOST DEPENDABLE, WITH RESPECT TO THEIR EXTENT AND RELIABILITY OF EXPOSURE REDUCTION."

WHEN THIS REPORT WAS PUBLISHED A FAIR AMOUNT OF WORK WAS ALREADY UNDERWAY AT A NUMBER OF FEDERAL AGENCIES, FOR CLEARLY, SOME HAD ALREADY BEEN DEALING WITH THESE TYPES OF ISSUES FOR A NUMBER OF YEARS. THE DEPARTMENT OF ENERGY, (DOE) THE ENVIRONMENTAL PROTECTION AGENCY (EPA) AND THE COMMISSION, AS WELL AS THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, (HUD) THE CENTER FOR DISEASE CONTROL, (CDC) THE NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH) THE NATIONAL INSTITUTE FOR ENVIRONMENTAL HEALTH SCIENCES (NIEHS) AND OTHER FEDERAL AGENCIES HAD PREVIOUSLY WORKED TOGETHER AS MEMBERS OF THE INTERAGENCY RESEARCH GROUP ON INDOOR AIR QUALITY. THIS GROUP HAD WORKED TO DEVELOP AN OVERALL STRATEGY ON INDOOR AIR QUALITY RESEARCH AND TESTING SO THAT THE PROJECTS OF THE VARIOUS AGENCIES COULD BE COORDINATED TO MEET DEFINED GOALS.

THE CPSC HAD BEEN INVOLVED BECAUSE MOST SOURCES OF INDOOR POLLUTANTS FALL UNDER ITS JURISDICTION. CPSC HAD BEEN INVOLVED WITH INDOOR POLLUTANTS, EITHER BECAUSE THE AGENCY HAD BEEN PETITIONED BY AN OUTSIDE GROUP TO TAKE ACTION, OR BECAUSE, ON ITS OWN, THE AGENCY HAD DECIDED THAT FURTHER INVESTIGATION WAS REQUIRED.

THE COMMISSION ACTED IN SEVERAL IMPORTANT CASES TO REDUCE CONSUMER EXPOSURE TO TOXIC CHEMICALS IN THE INDOOR AIR. CONSUMER PRODUCTS WHOSE USE WOULD HAVE RESULTED IN HAZARDOUS INDOOR AIR LEVELS OF KNOWN OR SUSPECTED CANCER-CAUSING CHEMICALS HAVE BEEN ISOLATED AND THE RISKS ADDRESSED. FOR EXAMPLE:

° VINYL CHLORIDE THIS CHEMICAL WAS A COMMON PROPELLANT USED IN AEROSOL SPRAYS. IT IS A KNOWN CARCINOGEN WHICH CARRIED AN EXCESS RISK OF 26 CANCERS PER MILLION PERSONS EXPOSED.

° ASBESTOS PATCHING COMPOUNDS PATCHING COMPOUNDS ARE USED FOR REPAIRS AND DRY WALL CONSTRUCTION IN THE HOUSEHOLD. ASBESTOS-BASED COMPOUNDS POSED A HEALTH RISK BECAUSE OF CONTACT EXPOSURE TO THE CARCINOGENIC MATERIAL.

° BENZENE PAINT STRIPPERS THIS CONSUMER PRODUCT IS ALSO USED IN HOME REPAIR WORK. BREATHING THE CHEMICAL DURING USE CAUSES AN EXCESS CANCER RISK ESTIMATED AT 29 PER MILLION EXPOSURES. THE COMMISSION PROPOSED A BAN, AND BY THAT ACTION ENERGIZED THE INDUSTRY TO SELECT SUBSTITUTE PRODUCTS FOR THIS PURPOSE. TODAY, AS A RESULT OF COMMISSION ATTENTION, THERE ARE NO KNOWN INSTANCES WHERE BENZENE IS INTENTIONALLY ADDED TO CONSUMER PRODUCTS.

IN ADDITION, OVER THE YEARS, THE AGENCY HAS REVIEWED VARIOUS CHEMICALS AND USES WHICH COULD PRESENT INDOOR AIR QUALITY HAZARDS SUCH AS N-HEXANE, BENZENE, AND AEROSOL SOLVENTS.

IT IS ONLY DURING THE PAST FEW YEARS, HOWEVER, THAT THE AGENCY HAS FOCUSED ITS ATTENTION ON THE QUALITY OF THE INDOOR ENVIRONMENT GENERALLY. IN SO DOING CPSC MOVED TO COMMIT A SIGNIFICANT PROPORTION OF ITS BUDGET AND STAFF RESOURCES TO THESE ISSUES. THE COMMISSION HAS CONSISTENTLY SELECTED INDOOR AIR QUALITY AS A PRIORITY PROJECT, COMMITTING CONTRACT DOLLARS AND STAFF TIME TO RESEARCH IN THESE AREA. THE COMMISSION HAS AGAIN SELECTED INDOOR AIR QUALITY AS A PRIORITY EFFORT IN FY 1984 AND FY 1985. IN FY 1983 THE COMMISSION PROVIDED A MILLION DOLLARS IN FUNDING FOR INDOOR AIR QUALITY AND WILL PROVIDE MORE THAN $1.3 MILLION IN FY 1984. ALTHOUGH THE COMMISSION HAS LIMITED RESOURCES WE ARE DEVOTING MORE STAFF TIME AND MONEY TO INDOOR AIR QUALITY THAN TO ANY OTHER ISSUE. TODAY WE ARE LOOKING INTO:

°INDOOR AIR POLLUTION FROM UNVENTED HEATING AND COOKING APPLIANCES SUCH AS GAS STOVES, KEROSENE HEATERS, GAS HEATERS AND WOOD AND COAL BURNING STOVES,

°FORMALDEHYDE OFFGASSING FROM PARTICLE BOARD AND PLYWOOD,

°VOLATILE ORGANICS SUCH AS BENZENE, PHTHALATES AND METHYLENE CHLORIDE FROM VARIOUS SOURCES IN THE HOME,

°ASBESTOS FIBERS IN THE HOME AIR FROM THE USE OF CONSUMER PRODUCTS THAT CONTAIN AND RELEASE ASBESTOS, AS WELL AS FROM THE USE OF ASBESTOS AS THERMAL INSULATION, AND IN HOUSEHOLD AND BUILDING MATERIALS.

SO FAR THIS YEAR THE COMMISSION HAS INVESTIGATED KEROSENE HEATERS AND UNVENTED GAS SPACE HEATERS TO DEFINE THE POLLUTANTS THAT ARE EMITTED DURING COMBUSTION AND TO DETERMINE THE LEVELS OF SUCH POLLUTANTS THAT CAN BUILD UP INDOORS.

UNVENTED GAS SPACE HEATERS, GAS STOVES AND KEROSENE HEATERS, LIKE OTHER UNVENTED APPLIANCES, EMIT THE PRODUCTS OF COMBUSTION DIRECTLY INTO THE INDOOR AIR. USE OF UNVENTED, PORTABLE HEATING APPLIANCES IS LIKELY TO CONTINUE OR INCREASE AS CONSUMERS SEEK ALTERNATIVE HEATING SOURCES IN THE FACE OF RISING ENERGY COSTS.

THE HAZARD TO THE MILLIONS OF FAMILIES WHO USE UNVENTED FUEL-FIRED APPLIANCES RESULTS FROM THE BY-PRODUCTS PRODUCED BY THE BURNING FLAME, (CARBON DIOXIDE, CARBON MONOXIDE, NITROGEN DIOXIDE, NITRIC OXIDE, SULFUR DIOXIDE, FORMALDEHYDE, PARTICULATES AND OTHERS). OF PARTICULAR CONCERN ARE THE EXPOSURES TO RESPIRATORY IRRITANTS, INCLUDING NITROGEN DIOXIDE, SULFUR DIOXIDE, AND FORMALDEHYDE. THESE POLLUTANTS MAY PARTICULARLY AFFECT INDIVIDUALS WITH PRE-EXISTING PULMONARY DISEASES SUCH AS BRONCHITIS, ASTHMA, AND EMPHYSEMA. THESE INDIVIDUALS CONSTITUTE OVER 10 PERCENT OF THE GENERAL POPULATION. SEVERAL STUDIES SUGGEST THAT EXPOSURE TO NITROGEN DIOXIDE INCREASES SUSCEPTIBILITY TO RESPIRATORY DISEASE, ESPECIALLY IN CHILDREN. CARBON MONOXIDE EXPOSURE IS OF PARTICULAR CONCERN FOR ANGINA PATIENTS.

THE SIGNIFICANCE OF THE CONTRIBUTION OF FUEL-FIRED APPLIANCES TO THE EXPOSURE OF AMERICANS TO HAZARDOUS POLLUTANTS IS DRAMATIZED BY A COMPARISON OF THE EXTENT OF THE POPULATION EXPOSURE THROUGH INDOOR VERSUS OUTDOOR POLLUTANT LEVELS. ACCORDING TO THE PRESIDENT'S COUNCIL ON ENVIRONMENTAL QUALITY (CEQ) ANNUAL REPORT, RELEASED IN JUNE 1983, 23.1 MILLION PERSONS WERE EXPOSED THROUGH OUTDOOR AIR TO "UNHEALTHFUL" NITROGEN DIOXIDE LEVELS (ABOVE 0.26 PPM) IN 1981. CEQ REPORTED THAT THE TOTAL NATIONAL EXPOSURE WAS 241 MILLION PERSON DAYS, 228 MILLION OF WHICH OCCURRED IN THE SOUTHERN CALIFORNIA COASTAL BASIN (LOS ANGELES AREA). CEQ REPORTS THAT THE PEOPLE EXPOSED TO "UNHEALTHY" OUTDOOR

LEVELS, OUTSIDE OF SOUTHERN CALIFORNIA, WERE ONLY EXPOSED, ON AVERAGE, TWO DAYS DURING THE YEAR.

THE CPSC'S STAFF UTILIZED THE AVAILABLE DATA ON CONSUMER USE OF KEROSENE AND UNVENTED GAS HEATERS AND THE LEVELS OF NITROGEN DIOXIDE IN HOMES ASSOCIATED WITH USE OF THESE APPLIANCES TO DEVELOP SIMILAR INFORMATION FOR INDOOR EXPOSURE. THE STAFF ESTIMATES THAT ABOUT ONE BILLION TO ONE AND ONE-HALF BILLION PERSON DAYS OF EXPOSURE TO "UNHEALTHY" LEVELS OF NITROGEN DIOXIDE OCCURRED DURING 1982 FROM CONSUMER USE OF UNVENTED GAS HEATERS AND KEROSENE HEATERS. SIGNIFICANTLY, AMERICAN CONSUMERS WERE EXPOSED TO THESE LEVELS IN AREAS OF "CLEAN" OUTDOOR AIR, AND THE EXPOSURES WERE LIKELY TO HAVE OCCURRED ON 90 TO 120 DAYS AND MAY HAVE LASTED FROM 6 TO 10 HOURS EACH DAY.

KEROSENE HEATERS

RESEARCHERS IN THE ENVIRONMENTAL HEALTH COMMUNITY HAD CONDUCTED LIMITED STUDIES WHICH INDICATED THE POTENTIAL FOR HAZARDOUS EMISSIONS OF VARIOUS POLLUTANTS, INCLUDING CARBON MONOXIDE, NITROGEN DIOXIDE AND SULFUR DIOXIDE, FROM KEROSENE HEATERS. IN OCTOBER, 1982, THE COMMISSION BEGAN AN INTENSIVE EIGHT-MONTH EFFORT WHICH CULMINATED IN OUR PUBLIC BRIEFING ON 5 JULY 1983. THIS INVESTIGATION - WHICH DEALT WITH THE FIRE AND BURN HAZARDS PRESENTED BY THE KEROSENE HEATER AS WELL AS THE INDOOR AIR QUALITY ASPECTS - RESULTED IN A COMPREHENSIVE ASSESSMENT OF THIS POTENTIAL SOURCE OF INDOOR POLLUTION AND IDENTIFIED SEVERAL SPECIFIC AREAS IN WHICH IMPROVEMENTS COULD BE MADE TO ASSURE THE GREATER SAFETY OF THE CONSUMER USING THESE APPLIANCES.

THE INDUSTRY, THROUGH ITS ASSOCIATION HAS UNANIMOUSLY ADOPTED THE MAJOR RECOMMENDATIONS AND WILL CONTINUE TO WORK WITH THE STAFF TOWARD THE SUCCESSFUL ADOPTION OF VOLUNTARY STANDARDS ON SUCH CRITICAL AREAS

AS TESTING REQUIREMENTS TO LIMIT THE CARBON MONOXIDE AND NITROGEN DIOXIDE EMISSION RATES. THE CPSC AND THE KEROSENE HEATER INDUSTRY ARE ALSO JOINTLY SUPPORTING INCREASED CONSUMER EDUCATION ON THE NEED FOR PROPER VENTILATION AND ENCOURAGING THE PETROLEUM INDUSTRY TO REDUCE THE LEVEL OF SULFUR IN KEROSENE AVAILABLE FOR CONSUMERS TO USE IN THESE HEATERS.

I BELIEVE THE RAPID AND COMPREHENSIVE COMMISSION INVESTIGATION OF KEROSENE HEATERS IS A TESTIMONIAL THAT INDOOR AIR QUALITY PROBLEMS CAN BE INVESTIGATED, AND SOLVED, AT REASONABLE COST AND WITHIN REASONABLE TIME FRAMES.

THE KEROSENE HEATER INDUSTRY, THROUGH THE NATIONAL KEROSENE HEATER ASSOCIATION, GAVE THEIR STRONG TECHNICAL AND MONETARY SUPPORT - FUNDING IN-HOME MONITORING STUDIES, CONSUMER USE SURVEYS, AND EXTENSIVE AND DETAILED COMPUTER MODELING OF HEAT-LOAD FACTORS AND DYNAMIC IN-HOME POLLUTANT LEVELS - AND WORKING WITH THE COMMISSION STAFF OPENLY AND PUBLICLY IN WEEK AFTER WEEK OF TECHNICAL MEETINGS - TOWARD THE ULTIMATE UNDERSTANDING OF THE INDOOR POLLUTION PROBLEM.

THE DIRECTORATE FOR HEALTH SCIENCES PREPARED A SERIES OF DOCUMENTS CONCERNING THE EMISSION, MATHEMATICAL MODELING, AND HEALTH EFFECTS, OF POLLUTANTS EMITTED BY KEROSENE HEATERS.

BASED ON OUR EVALUATION OF THE DATA, WE CONCLUDE THAT THE HEALTH HAZARD OF GREATEST SIGNIFICANCE IS THAT WHICH MAY BE PRESENTED BY EXPOSURE TO NITROGEN DIOXIDE. THE POTENTIAL FOR ADVERSE HEALTH EFFECTS, E.G. INCREASED RESPIRATORY ILLNESS, INCREASED AIRWAY RESISTANCE IN ASTHMATICS OR POSSIBLE LUNG DAMAGE, MAY EXIST IF HEATERS ARE TYPICALLY USED IN A CLOSED ROOM OR IN SOME SEMI-OPEN ROOM SITUATIONS. EFFECTS MAY BE MADE MORE SEVERE BY THE CONCOMITANT PRESENCE OF SULFUR DIOXIDE. THE

LEVEL OF CARBON MONOXIDE PRODUCED BY SOME HEATERS, PARTICULARLY WHEN THE WICK IS TURNED DOWN (A TYPICAL MALADJUSTMENT) IS ALSO OF CONCERN.

THE SIGNIFICANT FINDINGS ON INDOOR AIR POLLUTION CAN BE SUMMARIZED AS FOLLOWS:

CONSUMER USE OF KEROSENE HEATERS 1/

- ALMOST 90 PERCENT OF THE CONSUMER USE OF KEROSENE HEATERS IS IN SINGLE FAMILY DWELLINGS.
- THE PREDOMINANT USE OF THE HEATERS (OVER 80 PERCENT) IS IN THE FAMILY LIVING AREA (FAMILY ROOM, KITCHEN-DINING ROOM, LIVING ROOM, ETC.)
- 90 PERCENT OF THE CONSUMERS USE THE HEATERS IN A ROOM OPEN TO THE REST OF THE HOUSE.
- HEATERS ARE TYPICALLY USED FOR SUFFICIENTLY LONG INTERVALS (SIX TO TEN HOURS) TO ALLOW POLLUTANT CONCENTRATIONS TO REACH LEVELS NEAR STEADY STATE AND REMAIN THERE FOR SEVERAL HOURS.
- CONSUMERS DO NOT TEND TO MOVE THE HEATERS FROM ROOM TO ROOM.

THE AVAILABLE DATA DO NOT ALLOW THE DETERMINATION OF A THRESHOLD OF EFFECTS FOR NITROGEN DIOXIDE. THUS THE STAFF IS UNABLE TO ASSURE THAT ADVERSE HEALTH EFFECTS, E.G. INCREASED SUSCEPTIBILITY TO RESPIRATORY ILLNESS, WILL NOT OCCUR IN SUSCEPTIBLE POPULATIONS FROM EVEN LOW LEVELS OF NITROGEN DIOXIDE EXPOSURE WHICH MAY OCCUR DURING KEROSENE HEATER USE. THE AVAILABLE DATA, HOWEVER, DO NOT LEAD US TO CONCLUDE THAT THE GENERAL POPULATION IS LIKELY TO EXPERIENCE SIGNIFICANT ADVERSE EFFECTS FROM THE FOLLOWING USES DURING A HEATING SEASON OF KEROSENE HEATERS:

1/ INFORMATION FROM THE CONSUMER USE SURVEYS OF NATIONAL KEROSENE HEATER ASSOCIATION AND KERO-SUN.

- MOST SMALL TO MEDIUM (9000 TO 12000 BTU) BLUE FLAME HEATERS IN A TYPICAL CONSUMER USE SITUATION, EXCEPT CLOSED ROOMS.
- MOST WELL ADJUSTED WICK-TYPE HEATERS OF ALL SIZES IF USED IN A ROOM WHICH IS FULLY OPEN TO THE REST OF THE HOUSE OR WHERE THE DOOR OF THE ROOM IN WHICH THE HEATER IS USED IS OPEN ENOUGH TO ALLOW SUBSTANTIAL AIRFLOW TO THE REST OF THE HOUSE (MORE THAN TWO INCHES). 2/

CERTAIN SUSCEPTIBLE POPULATIONS MAY EXPERIENCE ADVERSE HEALTH EFFECTS FROM THE NITROGEN DIOXIDE LEVELS EMITTED BY WHITE FLAME AND WICKLESS HEATERS, EVEN WHEN USED IN AN OPEN ROOM. THESE ADVERSE EFFECTS COULD INCLUDE INCREASED SUSCEPTIBILITY TO RESPIRATORY ILLNESS AND INCREASED AIRWAY RESISTANCE IN ASTHMATICS. THE CONCOMITANT PRESENCE OF SULFUR DIOXIDE MAY EXACERBATE ANY PREDICTED RESPIRATORY EFFECTS.

TESTING HAS DEMONSTRATED THAT SOME WHITE FLAME HEATER MODELS HAD SIGNIFICANTLY LOWER RATES OF EMISSION OF NITROGEN DIOXIDE THAN DID OTHER MODELS. THIS OFFERS ENCOURAGEMENT THAT AVAILABLE TECHNOLOGY COULD REDUCE NITROGEN DIOXIDE EMISSION RATES AND THE POTENTIAL FOR ADVERSE HEALTH EFFECTS.

- DEVELOPMENT OF A VOLUNTARY STANDARD THAT WOULD LIMIT THE NITROGEN DIOXIDE EMISSION RATE SHOULD BE ENCOURAGED. WE RECOMMEND THAT 2.5×10^{-3} CC/KJ BE CONSIDERED AS A TARGET LEVEL. SOME BLUE FLAME HEATERS AND MOST WHITE FLAME HEATERS CURRENTLY EXCEED THAT LEVEL. LONG TERM EFFORTS SHOULD BE DIRECTED TOWARD FURTHER LOWERING OF THE EMISSION RATES,

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2/ THERE ARE NO DATA ON THE MIXING OF AIR THROUGH A SEMI-OPEN DOOR. MODELING WAS BASED ON MATHEMATICAL INTERPOLATION OF DATA FROM AIR FLOW THROUGH A FULLY OPEN DOOR TO A DOOR OPEN TWO INCHES.

RECOGNIZING THAT DIFFERENT RATES MAY BE APPROPRIATE FOR DIFFERENT SIZED HEATERS.

MEASUREMENTS IN HOMES HAVE SHOWN SOME SULFUR DIOXIDE LEVELS OF CONCERN. THESE LEVELS ARE NOT, IT APPEARS, DEPENDENT UPON THE HEATER TYPE BUT ON THE SULFUR CONTENT OF THE FUEL USED, THE AMOUNT OF FUEL CONSUMED BY THE HEATER AND THE RATE OF REACTIVE DECAY IN THE HOUSE ENVIRONMENT. WE DO NOT YET HAVE SUFFICIENT INFORMATION TO DETERMINE EXACTLY WHAT LEVEL OF SULFUR IN THE FUEL WILL CONSISTENTLY RESULT IN LEVELS OF SULFUR DIOXIDE BELOW THOSE WHICH ARE EXPECTED TO CONTRIBUTE TO ADVERSE HEALTH EFFECTS.

IN SUMMARY, THE MOST SIGNIFICANT POTENTIAL FOR A HEALTH HAZARD FROM KEROSENE HEATERS IS PRESENTED BY EXPOSURE TO NITROGEN DIOXIDE. THE POTENTIAL FOR LUNG DAMAGE MAY EXIST IF HEATERS ARE CONSISTENTLY USED IN A CLOSED ROOM, ESPECIALLY IN A TIGHT HOUSE. THE TECHNOLOGY TO LOWER THE NITROGEN DIOXIDE EMISSIONS OF WHITE FLAME HEATERS APPEARS AVAILABLE AS THE EMISSION RATES OF PROPERLY ADJUSTED HEATERS IN THE CPSC TESTING VARY FROM A LOW OF 2.31×10^{-3} CC/KJ TO A HIGH OF 6.85×10^{-3} CC/KJ. FOR PROPERLY ADJUSTED BLUE FLAME HEATERS THE NITROGEN DIOXIDE EMISSION RATES VARY FROM 1.85×10^{-3} CC/KJ TO 3.29×10^{-3} CC/KJ. EXPOSURES TO NITROGEN DIOXIDE SHOULD BE MINIMIZED TO THE EXTENT FEASIBLE.

UNVENTED GAS SPACE HEATERS

THE REPORT OF OUR PRELIMINARY INVESTIGATION OF POLLUTANT EMISSIONS FROM UNVENTED GAS SPACE HEATERS WILL BE PRESENTED TO THE CPSC COMMISSIONERS TOMORROW, 3 AUGUST 1983. CONSUMER EXPOSURE TO POLLUTANTS GENERATED BY UNVENTED GAS SPACE HEATERS HAS BEEN ESTIMATED FROM TESTING CONDUCTED FOR THE COMMISSION BY LAWRENCE BERKELEY LABORATORY (LBL). A CONTROLLED EXPERIMENTAL CHAMBER AND AN UNOCCUPIED HOUSE WERE USED BY LBL

TO DETERMINE EMISSION RATES AND POTENTIAL IN-HOUSE LEVELS OF NITROGEN DIOXIDE, NITRIC OXIDE, CARBON MONOXIDE, CARBON DIOXIDE, FORMALDEHYDE AND PARTICULATES.

HEALTH SCIENCES STAFF MODELED THE EMISSION RATES FOR THE FOUR UNVENTED GAS SPACE HEATERS WHICH LBL TESTED IN THE HOUSE, TO VARIOUS CONSUMER USE SCENARIOS. THE MODELED POLLUTANT LEVELS ARE COMPARED TO DATA ON HEALTH EFFECTS IN A HAZARD ANALYSIS OF THE POTENTIAL HEALTH EFFECTS FROM THE USE OF UNVENTED GAS SPACE HEATERS.

THE MEASURED AND PREDICTED LEVELS OF CARBON MONOXIDE, CARBON DIOXIDE, NITROGEN DIOXIDE AND FORMALDEHYDE EMITTED BY SOME HEATERS ARE SUFFICIENTLY HIGH TO MERIT FURTHER STUDY AND TO CAUSE CONCERN ABOUT POTENTIAL HEALTH EFFECTS TO CONSUMERS CURRENTLY USING THE PRE-ODS MODEL HEATERS AND SIMILAR MODEL HEATERS WITH ODSS. AN ESTIMATED 5.5 MILLION UNVENTED GAS SPACE HEATERS ARE CURRENTLY IN USE. CURRENT STAFF INFORMATION IS THAT THERE WOULD BE NO SIGNIFICANT TECHNOLOGICAL DIFFERENCES AMONG MOST HEATERS IN USE AND THOSE TESTED. HOWEVER, THE EFFECT OF AGE AND WEAR ON POLLUTANT EMISSIONS ARE UNKNOWN.

THE COMMISSION STAFF CONCLUDED, BASED ON THIS PRELIMINARY STUDY, THAT UNVENTED GAS SPACE HEATERS APPEAR TO PRESENT A RISK TO CONSUMERS THROUGH THE POLLUTANT EMISSIONS ASSOCIATED WITH NORMAL USE AND REASONABLY FORESEEABLE MISUSE. THIS RISK INCREASES WITH INCREASING HEATER SIZE AND DECREASING VENTILATION.

THE DIRECTORATE FOR HEALTH SCIENCES HAS A CONTRACT WITH THE LBL TO DO ADDITIONAL TESTING ON NEW MODELS OF UNVENTED GAS SPACE HEATERS EQUIPPED WITH OXYGEN DEPLETION SENSORS.

THE NEW TESTING WILL PROVIDE A LARGER DATA BASE OF EMISSION DATA AND REFLECT ANY CHANGES IN EMISSION CHARACTERISTICS ASSOCIATED WITH THE

NEW HEATERS. TESTING OF UNVENTED GAS SPACE HEATERS HAS ALSO BEEN CONDUCTED FOR THE GAS RESEARCH INSTITUTE (GRI) AND BY THE AMERICAN GAS ASSOCIATION LABORATORIES (AGAL). THESE DATA HAVE BEEN ANALYZED BY THE DIRECTORATE FOR HEALTH SCIENCES. THE RANGES OF DATA OVERLAP, BUT THE AGAL DATA IS GENERALLY LOWER THAN THE LBL DATA. DIFFERENCES IN TESTING METHODS MAY ACCOUNT FOR THE DIFFERENCE. AGAL HAS ALSO CONDUCTED RESEARCH INTO LOWERING THE NITROGEN OXIDE EMISSIONS OF GAS BURNERS FOR VARIOUS APPLIANCES.

AS A RESULT OF A 16 JUNE 1983 MEETING BETWEEN COMMISSION STAFF AND REPRESENTATIVES OF GRI, AGA, AGAL AND NATURAL GAS AND LP APPLIANCE MANUFACTURERS, THE INDUSTRY HAS AGREED TO FORM A TASK FORCE TO WORK WITH THE STAFF TO DEVELOP THE ADDITIONAL INFORMATION NEEDED TO FULLY CHARACTERIZE POTENTIAL CONSUMER EXPOSURE TO POLLUTANT EMISSIONS FROM UNVENTED GAS SPACE HEATERS.

SUMMARY OF COMBUSTION EMISSIONS RESEARCH

ONE OF THE MOST SIGNIFICANT ASPECTS OF THE COMMISSION'S RESEARCH IN INDOOR AIR QUALITY HAS BEEN THE ABILITY OF ITS IN-HOUSE STAFF TO DEVELOP EXPOSURE INFORMATION AND COMBINE THAT WITH AN IN-DEPTH TOXICOLOGICAL ANALYSIS TO FORM A HAZARD ASSESSMENT. DURING THE COMMISSION'S EVALUATION OF THE EFFECTS OF FUEL-FIRED APPLIANCES ON INDOOR AIR QUALITY, THE STAFF PREPARED DETAILED ANALYSIS OF THE AVAILABLE TOXICOLOGICAL DATA ON THE HEALTH EFFECTS ASSOCIATED WITH THE EXPOSURE TO CARBON DIOXIDE, CARBON MONOXIDE, FORMALDEHYDE, NITROGEN DIOXIDE AND SULFUR DIOXIDE.

DATA FROM ANIMAL AND HUMAN STUDIES SHOW THAT EXPOSURE TO EACH OF THESE POLLUTANTS HAS BEEN ASSOCIATED WITH ADVERSE HEALTH EFFECTS.

OVERALL, THE HEALTH SCIENCES STAFF CONCLUDED THAT THESE DATA SUGGEST THAT LEVELS AT WHICH HEALTH EFFECTS MAY BE NOTED IN SUSCEPTIBLE POPULATIONS FOR THESE POLLUTANTS ARE 15 PPM CO, ABOUT 1% CO_2, 0.1 PPM NO_2, AND 0.1 PPM SO_2. IT SHOULD BE NOTED THAT THESE ARE LEVELS FOR INDIVIDUAL POLLUTANTS AND THAT EFFECTS FOR COMBINED POLLUTANTS MAY OCCUR AT LOWER LEVELS.

THE COMMISSION STAFF EFFORTS AT EVALUATING WHETHER THESE POLLUTANTS PRESENTED AN "UNREASONABLE RISK", THE STATUTORY LANGUAGE OF THE CONSUMER PRODUCT SAFETY ACT, REQUIRED AN EVALUATION OF THE HEALTH EFFECTS DATA THAT WAS DIFFERENT IN CONCEPT FROM THAT USED IN ESTABLISHING THE OUTDOOR AMBIENT AIR QUALITY STANDARDS. OUR GOAL WAS TO PROVIDE GUIDANCE TO OUR COMMISSIONERS AND TO THE AFFECTED INDUSTRY ON THE NATURE, DURATION AND LEVEL OF EXPOSURE WHICH WOULD PRESENT A RISK OF INJURY THAT WAS NOT BALANCED BY THE ECONOMIC OR SOCIETAL BENEFITS THAT COULD BE DERIVED FROM THE PRODUCT. I BELIEVE THE COMMISSION IS THE ONLY AGENCY NOW DEALING WITH INDOOR AIR QUALITY THROUGH THIS COMPLEX EXERCISE OF BALANCING RISKS AND BENEFITS.

THE COMMISSION HAS A CLEAR ROLE IN THE PROTECTION OF THE PUBLIC HEALTH THROUGH CONTROL OF SOURCES OF INDOOR POLLUTANTS. THERE IS A PUBLIC NEED FOR ALTERNATIVE HEATING SOURCES, AND THE COMMISSION HAS DEMONSTRATED THAT IT CAN WORK COOPERATIVELY WITH OTHER FEDERAL AGENCIES AND WITH THE INDUSTRY TO PROVIDE THE PUBLIC WITH SAFER ALTERNATIVE HEATING SOURCES.

THE OTHER UNIQUE ASPECT OF THE COMMISSION'S EFFORTS IN THIS PRIORITY PROJECT HAS BEEN OUR ABILITY TO ACTIVELY INVOLVE THE AFFECTED INDUSTRY IN THE RESEARCH. THE INDUSTRY COMMITMENT OF TECHNICAL EXPERTISE AND RESEARCH DOLLARS DEMONSTRATED A POSITIVE AND CONSTRUCTIVE

APPROACH WHICH CAN, I BELIEVE, BE SUCCESSFULLY APPLIED TO OTHER "SOURCE CONTROL" ASPECTS OF INDOOR AIR QUALITY. OUR JOINT EFFORT HAS DEMONSTRATED A TIMELY AND SUCCESSFUL RESOLUTION OF AN INDOOR AIR QUALITY PROBLEM. THE INDUSTRY IS NOW WORKING ON HEATER REDESIGN WHICH SHOULD ASSURE THE ADOPTION, BEFORE THE 1984-85 HEATING SEASON OF VOLUNTARY STANDARDS TO REDUCE THE POTENTIAL OF HAZARDOUS EXPOSURE TO NITROGEN DIOXIDE AND CARBON MONOXIDE.

WE INTEND TO APPLY THIS CONCEPT OF COOPERATIVE INDUSTRY - CPSC FUNDED RESEARCH TO OUR CONTINUING WORK ON UNVENTED GAS SPACE HEATERS AND GAS STOVES. A NEW EUROPEAN STYLE GAS HEATER, CALLED A CABINET HEATER, WILL ALSO BE SUBJECTED TO THE SAME EMISSIONS EVALUATION AS IT BECOMES AVAILABLE FOR SALE IN THE UNITED STATES. OTHER NEW TECHNOLOGIES WILL BE EMERGING IN THIS FIELD, E.G., CATALYTIC HEATERS, AND WILL REQUIRE EVALUATION AND STANDARDS SETTING. LIKEWISE, EVALUATION OF EMISSIONS FROM COAL AND WOOD BURNING STOVES IS PLANNED DURING FY 1984. WE HOPE THAT JOINT COOPERATION WITH THESE INDUSTRIES AND VOLUNTARY STANDARDS SETTING ORGANIZATIONS WILL BE AS SUCCESSFUL AS OUR EFFORTS WITH THE KEROSENE HEATER INDUSTRY.

PARTICLEBOARD/PLYWOOD

THE COMMISSION IS ALSO APPLYING THE CONCEPT OF JOINT INDUSTRY - CPSC COOPERATION IN RESEARCHING THE INDOOR AIR QUALITY PROBLEM PRESENTED BY FORMALDEHYDE EMISSIONS FROM PRESSED WOOD PRODUCTS.

MOST INTERIOR GRADES OF PARTICLEBOARD AND PLYWOOD (INCLUDING WALL PANELING) ARE MANUFACTURED WITH UREA-FORMALDEHYDE RESINS WHICH SERVE AS AN ADHESIVE/BINDER. THE COMMISSION IS AWARE OF A SUBSTANTIAL NUMBER OF REPORTS OF ADVERSE HEALTH EFFECTS FROM MOBILE AND CONVENTIONAL HOME

RESIDENTS WHOSE SYMPTOMS ARE BELIEVED TO BE RELATED TO FORMALDEHYDE EMISSION FROM THESE PRODUCTS.

DURING FY 1982, THE OAK RIDGE NATIONAL LABORATORY (ORNL) DEVELOPED, UNDER CONTRACT TO THE COMMISSION, A DEVICE FOR MEASURING FORMALDEHYDE EMISSIONS DIRECTLY FROM THE PRODUCT SURFACE. THIS DEVICE, CURRENTLY UNDER DEVELOPMENT, MAY BE USEFUL TO INDUSTRY IN IMPROVING ITS EXISTING TEST METHODS FOR MEASURING FORMALDEHYDE AS PART OF A QUALITY CONTROL PROCESS.

BECAUSE OF A GROWING CONCERN ABOUT THE ACUTE AND CHRONIC HEALTH EFFECTS OF FORMALDEHYDE GAS AND BECAUSE OF A CONTINUING INCREASE IN CONSUMER COMPLAINTS, THE COMMISSION INITIATED A PROJECT TO QUANTIFY THE EXTENT OF THE RISK TO CONSUMERS FROM FORMALDEHYDE RELEASED BY THESE PRODUCTS. THE FORMALDEHYDE PROBLEM FROM PRESSED WOOD IN MOBILE HOMES IS WIDELY RECOGNIZED THROUGHOUT GOVERNMENT AND INDUSTRY, AND IS SEVERE ENOUGH TO PROMPT HUD TO INITIATE ACTION TO DEVELOP A MANDATORY STANDARD TO LIMIT FORMALDEHYDE EMISSIONS IN MOBILE HOMES. ALTHOUGH THESE WOOD PRODUCTS HAVE BEEN USED FOR MANY YEARS IN MOBILE AND CONVENTIONAL HOMES, THE ADVERSE HEALTH EFFECTS FROM THE PRODUCTS ARE ONLY NOW COMING TO THE ATTENTION OF GOVERNMENT.

THE COOPERATION AND THE SHARING OF RESEARCH PLANNING AND DATA BETWEEN CPSC AND THE WOOD PRODUCTS INDUSTRY HAS LED TO VOLUNTARY PRODUCT IMPROVEMENTS IN A NON-ADVERSARIAL MANNER. MANUFACTURERS OF PRESSED WOOD PRODUCTS HAVE INFORMED THE COMMISSION THAT THEY HAVE REDUCED FORMALDEHYDE EMISSIONS FROM THEIR PRODUCTS BY 70 TO 90 PERCENT SINCE THE MID-1970'S. THE WORK THE COMMISSION IS CURRENTLY PERFORMING WILL DETERMINE IF THAT FIGURE IS ACCURATE; AND WHETHER THE REDUCTION IS SUFFICIENT TO ADEQUATELY ADDRESS THE RISK OF INJURY FROM FORMALDEHYDE.

VOLATILE ORGANIC COMPOUNDS (VOC'S)

THE AVAILABLE DATA BASE ON RESIDENTIAL POLLUTANTS, (I.E., THE IDENTIFICATION OF POLLUTANTS, THEIR LEVELS, DAILY AND SEASONAL VARIATIONS, PEAK LEVELS, ETC.) THEIR SOURCES AND IMPACT ON HEALTH IS VERY LIMITED. THE AVAILABLE DATA HAS BEEN GENERATED BY A SERIES OF PILOT STUDIES AND DOES NOT FULLY CHARACTERIZE THE RANGE OF POLLUTANTS. STUDIES EXPLICITLY ADDRESSING BOTH LONG-TERM AND EPISODIC EVENTS HAVE NOT BEEN UNDERTAKEN.

THERE IS ALSO A LACK OF INFORMATION ABOUT THE LEVELS OF VOLATILE ORGANICS WHICH OCCUR IN THE HOME FROM THE USE OF A LARGE NUMBER OF CONSUMER PRODUCTS SUCH AS AEROSOL PROPELLANTS, SOLVENTS, COMPONENTS OF PLASTICS, CLEANERS, POLISHES, PAINTS AND VARNISHES, ETC.

TO ADDRESS THIS PROBLEM THE COMMISSION UNDERTOOK A STUDY AT THE ORNL TO MONITOR 40 RESIDENCES FOR POLLUTANTS OVER A NINE MONTH PERIOD. ALL HOUSES WERE SYSTEMATICALLY MONITORED FOR FORMALDEHYDE, CARBON MONOXIDE, CARBON DIOXIDE, NITROGEN OXIDES, VOLATILE ORGANIC CHEMICALS AND PARTICULATES. IN ADDITION, FACTORS SUCH AS TEMPERATURE, HUMIDITY, AIR EXCHANGE RATE, AND OTHER METEOROLOGICAL FACTORS WHICH CAN AFFECT THE POLLUTANT LEVELS WERE ALSO MONITORED.

THE 40 HOMES IN THIS STUDY WERE MONITORED TWICE EACH DURING THE SPRING/SUMMER MONTHS AND ONCE DURING THE WINTER MONTHS. THE AIR WAS SAMPLED FOR 24 HOURS USING A TENAX SORBANT MEDIA. THE NUMBER OF VOCS OBSERVED IN THESE HOMES VARIED FROM 20 TO OVER 150. THE NUMBER AND CONCENTRATIONS OF VOCS WERE MUCH GREATER INDOOR THAN OUTDOORS. SEVENTEEN PEAKS THAT WERE PRESENT MOST CONSISTENTLY AND AT HIGHER LEVELS IN THE TEST HOMES WERE IDENTIFIED AND QUANTITATED. THE LEVELS OF THESE SEVENTEEN VOCS, WHICH INCLUDED BENZENE, TOLUENE, ETHYLBENZENE, XYLENE, CUMENE, BENZALDEHYLDE, MESITYLENE, LIMONENE, NAPTHALENE, 2-METHYL-NAPHTHALENE, DIETHYL PHTHALATE, DODECANE, TRIDECANE, TETRADECANE, PENTADECANE AND HEXADECANE, WERE GENERALLY TEN TIMES GREATER INDOORS THAN OUTDOORS. MANY OF THE MORE HIGHLY VOLATILE ORGANICS WHICH PASSED THROUGH THE TENAX COLUMN MAY BE OF ACTUALLY GREATER TOXICOLOGICAL CONCERN. THESE INCLUDE HALOGENATED HYDROCARBONS SUCH AS METHYLENE CHLORIDE AS WELL AS LOWER MOLECULAR WEIGHT ALDEHYDES AND MONOMERS THAT MAY BE RELEASED FROM PLASTICS AND RESINS.

AN ATTEMPT TO DEFINE HIGHLY VOLATILE ORGANICS USING A CARBON/SILICA GEL/TENAX COLUMN FOR COLLECTION WITH A REDUCED AIR SAMPLING TIME (30 MINUTES VS 24 HOURS) SHOWED PROMISE. THE RESULTS SUGGESTED THE PRESENCE OF METHYLENE CHLORIDE, DI- AND TRI-CHLOROETHANE; PERCHLOROETHYLENE; DI- AND TRI-CHLOROPROPANE AND BENZENE.

IN ORDER TO DETERMINE THE POTENTIAL HAZARDS ASSOCIATED WITH EXPOSURE TO VOLATILE ORGANIC POLLUTANTS IDENTIFIED BY ORNL IN RESIDENTIAL INDOOR AIR, HEALTH SCIENCES HAS CONDUCTED PRELIMINARY TOXICOLOGICAL EVALUATIONS OF SELECTED CHEMICALS. THOSE SELECTED WERE PRESENT IN VIRTUALLY ALL OF THE HOMES TESTED.

BRIEFLY, BENZENE IS A RECOGNIZED HUMAN CARCINOGEN CAUSING LEUKEMIA. IT ALSO CAN CAUSE DISORDERS OF THE BONE MARROW INCLUDING PANCYTOPENIA AND ANEMIA. FORMALDEHYDE IS A STRONG IRRITANT, A SENSITIZER, A RECOGNIZED ANIMAL CARCINOGEN AND A SUSPECTED HUMAN CARCINOGEN. EXPOSURE TO FORMALDEHYDE CAN PRODUCE IRRITATION OF THE EYE, NOSE AND THROAT, COUGHING, WHEEZING, DIARRHEA AND ALLERGIC CONTACT DERMATITIS AND ASTHMA. BENZALDEHYDE AND LIMONENE ARE BOTH IRRITANTS AND SENSITIZERS. CUMENE IS AN IRRITANT AND CAN CAUSE LIVER, LUNG AND KIDNEY DAMAGE. MOST OF THE REMAINING VOLATILE ORGANICS ARE IRRITANTS TO MUCOUS MEMBRANES AND ARE

CENTRAL NERVOUS SYSTEM DEPRESSANTS. TOLUENE, XYLENE AND DIETHYL PHTHALATE ARE ADDITIONALLY EMBRYOTOXIC AND/OR TERATOGENIC IN ANIMALS. DODECANE AND HEXADECANE ENHANCE THE MUTATION FREQUENCY IN BACTERIA SYSTEMS AND INCREASE THE TUMOR INCIDENCE IN ANIMALS.

PERCHLOROETHYLENE (PERC) CAUSED CENTRAL NERVOUS SYSTEM (CNS), LIVER AND KIDNEY DAMAGE AND, FOLLOWING CHRONIC EXPOSURE, IS A POSSIBLE MUTAGEN AND AN ANIMAL CARCINOGEN. METHYLENE CHLORIDE CAUSES CNS EFFECTS, CARDIAC DEPRESSION AND CARDIAC SENSITIZATION. IT HAS BEEN REPORTED TO BE AN ANIMAL CARCINOGEN AND IS MUTAGENIC IN SEVERAL TEST SYSTEMS.

1,2-DICHLOROETHANE CAUSES LIVER AND KIDNEY DAMAGE AND ITS METABOLITE, CHLOROACETALDEHYDE, IS MUTAGENIC. 1,2,3-TRICHLOROPROPANE IS MUTAGENIC WHILE 1,2-DICHLOROPROPANE IS HEPATOTOXIC. AT PRESENT WE DO NOT KNOW THE HEALTH EFFECTS OF MOST OF THESE CHEMICALS IN HUMANS AT THE EXPOSURE LEVELS FOUND IN THE HOMES. ESTIMATION OF POTENTIAL HUMAN HEALTH EFFECTS WILL REQUIRE MORE DETAILED EVALUATION AND ANALYSIS OF THE LITERATURE AND MONITORING DATA.

ASBESTOS IN THE HOME

LARGE QUANTITIES OF LOOSELY BOUND ASBESTOS MATERIAL HAVE BEEN USED IN HOMES IN A WIDE VARIETY OF WAYS. MANY OF THESE USES HAVE LEFT EXPOSED ASBESTOS THAT IS SUBJECTED TO WEAR AND DAMAGE OVER THE LIFE OF A HOME. THE DEGREE OF RISK TO CONSUMERS FROM IN-PLACE ASBESTOS REMAINS TO BE ESTABLISHED; HOWEVER, THE NATIONAL ACADEMY OF SCIENCES' COMMITTEE ON INDOOR AIR POLLUTION HAS CONCLUDED THAT PAST HOME USES OF ASBESTOS MAY PRESENT A GREATER PROBLEM THAN ASBESTOS IN SCHOOLS. THE EPA STAFF HAS ESTIMATED THAT THE ASBESTOS NOW PRESENT IN SCHOOLS MAY EVENTUALLY CAUSE UP TO 6,700 CANCERS IN EXPOSED TEACHERS AND STUDENTS (BEST ESTIMATE 1,100 CANCERS).

BECAUSE OF ITS USEFUL PROPERTIES, ASBESTOS HAS FOUND USE IN MANY DIFFERENT HOME APPLICATIONS. TODAY, BECAUSE OF GOVERNMENT ACTION AND GENERAL CONCERN ABOUT ASBESTOS HEALTH HAZARDS, CONSUMER PRODUCT APPLICATIONS OF ASBESTOS HAVE MARKEDLY DECREASED. WITH THE EXCEPTION OF THE LIMITED GROUP OF PRODUCTS ADDRESSED IN THE ASBESTOS-IN-PRODUCTS PROJECTS, CPSC'S CONCERN IS NOW OLD ASBESTOS PRODUCTS STILL PRESENT IN HOMES.

BOTH PUBLIC AND EXPERT CONCERN ABOUT ASBESTOS-IN-HOMES HAS INCREASED IN THE LAST FEW YEARS; A NUMBER OF RECENT OCCURRENCES HAVE HIGHLIGHTED THIS CONCERN.

- CONSUMER REQUESTS QUICKLY EXHAUSTED THE FIRST PRINTING OF 10,000 COPIES OF THE ASBESTOS IN THE HOME BOOKLET THAT CPSC JOINTLY PREPARED WITH EPA; ANOTHER 10,000 COPIES HAVE BEEN PRINTED AND HALF ARE NOW GONE.
- EPA HAS DETERMINED THAT ASBESTOS USE IN BUILDINGS OTHER THAN SCHOOLS IS A MAJOR CONCERN, AND IS BEGINNING A NATIONAL STUDY TO EVALUATE THIS PROBLEM ON AN URGENT BASIS. THE EPA EFFORT IS DIRECTED TOWARDS LARGE BUILDING, AND THE EPA STAFF FEELS THAT CPSC WORK TO STUDY INDIVIDUAL HOMES AND APARTMENTS IS CRITICAL.
- OFFICIALS OF THE CALIFORNIA STATE HEALTH DEPARTMENT HAVE MET WITH CPSC; THEY HAVE INITIATED A PROGRAM TO STUDY IN-HOME ASBESTOS, AND ARE PARTICULARLY CONCERNED ABOUT USES OF ASBESTOS INSIDE OLDER HOT AIR FURNACES.

DESPITE THE LARGE NUMBERS OF CONSUMER REPORTS THAT CPSC HAS RECEIVED, THE ACTUAL QUANTITY AND NATURE OF ASBESTOS USES IN THE HOME ARE LARGELY UNKNOWN. A MAJOR EFFORT TO FILL THIS GAP IN KNOWLEDGE IS

BEING UNDERTAKEN BY THE AMERICAN SOCIETY OF HOME INSPECTORS (ASHI). ASHI HAS INITIATED A SURVEY OF HOMES INSPECTED BY THEIR MEMBERS TO DETERMINE THE ASBESTOS MATERIALS PRESENT AND THE CONDITION OF THOSE MATERIALS.

RESEARCH NEEDS

COMBUSTION EMISSIONS

IN THE AREA OF INDOOR POLLUTANT EXPOSURES FROM FUEL-FIRED APPLIANCES SEVERAL TYPES OF RESEARCH TO FULLY CHARACTERIZE EXPOSURES, DEFINE POTENTIAL HEALTH EFFECTS FROM THESE EXPOSURES, AND DEVELOP APPROPRIATE PRODUCT STANDARDS MUST CONTINUE. THESE INCLUDE:

- LABORATORY EMISSION TESTING TO DETERMINE SOURCE STRENGTH
- FIELD (IN-HOME) MONITORING STUDIES TO DETERMINE ACTUAL EXPOSURE
- MODELING STUDIES TO PROJECT POPULATION EXPOSURE UNDER A VARIETY OF CONDITIONS WHICH AFFECT OCCUPIED IN-DOOR SPACES. THIS RESEARCH SHOULD BE COORDINATED AMONG THE INTERESTED FEDERAL AGENCIES (DOE, EPA, CPSC, ETC.) AND AFFECTED INDUSTRY AND PRIVATELY FUNDED ORGANIZATIONS.

HEALTH EFFECTS

IN ORDER TO BETTER ASSESS THE POTENTIAL FOR ADVERSE EFFECTS, A CLINICAL STUDY, DONE IN COOPERATION WITH THE OTHER AGENCIES, (EPA, DHHS, DOE, ETC.) SHOULD BE CARRIED OUT TO DETERMINE THE EFFECT ON ASTHMATICS OF LOW LEVEL EXPOSURE TO SO_2 AND NO_2, INDIVIDUALLY AND COMBINED IN HOUSEHOLD AIR. A SIMILAR STUDY ON THE AFFECTS ON ANGINA PATIENTS OF EXPOSURE TO CARBON MONOXIDE IS ALSO NEEDED. THESE STUDIES SHOULD ALSO ESTIMATE THE CLINICAL SIGNIFICANCE OF RESPONSES SO AS TO ALLOW FOR A DETERMINATION OF THE RISKS AND COSTS OF SUCH EFFECTS.

MORE IN-DEPTH STUDIES OF THE ADVERSE EFFECTS OF NO_2 ON HUMANS ARE NEEDED. THE POTENTIAL FOR PROLONGED LOW-LEVEL EXPOSURE TO CAUSE CELLULAR AND STRUCTURAL DAMAGE TO THE LUNG NEEDS FURTHER INVESTIGATION. THE EXPOSURE LEVELS AT WHICH THESE EFFECTS OCCUR, AND WHETHER THE CELLULAR AND STRUCTURAL DAMAGE MAY LEAD TO EMPHYSEMA IN HUMANS IS OF SERIOUS CONCERN AND MUST BE CAREFULLY RESEARCHED. THESE DATA WOULD BE OF BENEFIT TO SEVERAL AGENCIES AND THE RESEARCH SHOULD BE DONE COOPERATIVELY.

FIELD STUDIES ON MULTIPLE POLLUTANTS

COMPREHENSIVE EXPOSURE DATA AND CONSUMER USE INFORMATION ARE NECESSARY TO RELATE AND COMPARE VARIOUS INDOOR SOURCES OF COMBUSTION POLLUTANTS, AS WELL AS VOLATILE ORGANICS AND OTHER CHEMICALS RELEASED INTO THE INDOOR AIR FROM USE OF CONSUMER PRODUCTS.

A MAJOR FIELD STUDY CONSISTING OF THREE PARTS SHOULD BE UNDERTAKEN:

- MONITORING YEAR-ROUND IN HOMES WHERE COMBUSTION APPLIANCES OR OTHER POLLUTANT SOURCES OF INTEREST ARE USED - THIS SHOULD INCLUDE AS REPRESENTATIVE A SECTION OF THE POPULATION AS POSSIBLE.
- CONSUMER USE SURVEYS TO DOCUMENT PRESENCE AND NORMAL USE OF PRODUCTS, APPLIANCES, OR BUILDING MATERIALS WHICH ARE SOURCES OF INDOOR AIR POLLUTION
- HEALTH EFFECTS SURVEYS OF HOMES WITH AND WITHOUT COMBUSTION APPLIANCES, (GAS RANGES AND OVENS, UNVENTED HEATERS, COAL/WOOD STOVES) TO EVALUATE EFFECTS OF EXPOSURE TO POLLUTANTS FROM COMBUSTION APPLIANCES.

IF POSSIBLE, SUCH A MAJOR STUDY SHOULD ALSO PROVIDE DATA ON CONSUMER EXPOSURE TO VOLATILE ORGANIC CHEMICALS FROM CONSUMER PRODUCT USE.

PASSIVE MONITOR DEVELOPMENT

RESEARCH TO DEVELOP PASSIVE MONITORS FOR NEARLY ALL CONTAMINANTS, AND TO VALIDATE THEM AND DEVELOP COMPARABILITY DATA THROUGH USE IN OCCUPIED HOMES NEEDS TO CONTINUE. PASSIVE MONITORS ARE ESSENTIAL TO LARGE SCALE SURVEY STUDIES. THEY ARE ALSO USEFUL, AS WE HAVE SEEN WITH FORMALDEHYDE AND RADON, TO GIVE CONSUMERS A RELATIVELY LOW COST MEANS TO EVALUATE WHETHER POTENTIALLY HAZARDOUS LEVELS OF POLLUTANTS ARE PRESENT IN THE INDOOR AIR AND TO TAKE REMEDIAL ACTION, IF WARRANTED.

ASBESTOS-IN-THE HOME

SURVEYS ARE NEEDED TO DETERMINE THE EXTENT AND CONDITION OF EXISTING IN-PLACE ASBESTOS MATERIALS IN HOMES. TO ENABLE MEANINGFUL EVALUATION OF THE HAZARD THAT THESE IN-PLACE MATERIALS PRESENT, DATA IS NEEDED ON ACTUAL LEVELS OF ASBESTOS FIBERS IN POTENTIAL PROBLEM HOMES.

INTERAGENCY COORDINATION

A COORDINATED PROGRAM OF INDOOR AIR QUALITY RESEARCH IS CLEARLY NEEDED. COORDINATED RESEARCH PLANNING WOULD BE ENHANCED THROUGH A MECHANISM SUCH AS THE FEDERAL COMMITTEE ON INDOOR AIR QUALITY CO-CHAIRED BY CPSC, THAT WAS SUGGESTED BY THIS COMMITTEE.

CPSC HAS OFTEN EXPRESSED ITS CONCERN AND COMMITTED SIGNIFICANT RESOURCES TO EFFORTS TO ASSURE THE QUALITY OF INDOOR AIR. CPSC IS COMMITTED TO TAKING THE NECESSARY ACTIONS TO ASSURE THAT THE MANY CONSUMER PRODUCTS UNDER OUR JURISDICTION DO NOT ENDANGER THE PUBLIC HEALTH THROUGH POLLUTANT EMISSIONS INTO THE INDOOR AIR. WE ARE A SMALL AGENCY AND THE RESEARCH NEEDS I'VE OUTLINED TODAY ARE CLEARLY BEYOND OUR CAPABILITIES. HOWEVER, THROUGH A COORDINATED EFFORT CPSC, EPA, DOE, DHHS AND OTHER AGENCIES CAN DEVELOP THE EXPOSURE AND HEALTH EFFECTS DATA NECESSARY FOR GOOD PUBLIC POLICY DECISION MAKING ON THIS MATTER VITAL TO THE HEALTH AND SAFETY OF OUR PEOPLE.

I HAVE BROUGHT WITH ME EXCERPTS FROM STAFF DOCUMENTS WHICH PROVIDE MORE DETAILED DATA ON THE FINDINGS OF OUR INDOOR AIR QUALITY RESEARCH. I WOULD LIKE TO SUBMIT THEM FOR THE RECORD.

THIS CONCLUDES MY PREPARED STATEMENT. I WOULD BE HAPPY TO ANSWER ANY QUESTIONS YOU MAY HAVE.

EXCERPTS FROM THE BRIEFING PACKAGE

KEROSENE HEATERS

PROJECT STATUS REPORT AND STAFF RECOMMENDATIONS

JUNE 23, 1983

CONSUMER PRODUCT SAFETY COMMISSION

PREPARED BY:

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EMISSIONS EVALUATION

The CPSC program of chamber testing kerosene heaters consisted of duplicate tests on each of 12 heaters. The 12 heaters represented:

- wick-fed blue-flame radiant heaters (4)
- wick-fed blue-flame convection heaters (3)
- wick-fed white-flame convection heaters (4)
- wickless heater (1).

The pollutant generation rates for these heaters show, as depicted in Figure 15, that blue-flame heaters as a group, whose flame temperature is lower than the white-flame heaters, generated NO_2 at about 50% of the rate of white-flame heaters. Conversely, the lower temperature of the blue-flame heaters, which results in reduced combustion efficiency, produced CO at nearly 5-times the rate of the white-flame heaters. Maladjustment of wick height can result in a 2-fold to 4-fold increase in the production of CO.

The Health Sciences' staff, the kerosene-heater industry, and others have used mass-balance models for predicting pollutant levels in homes or buildings. A modeling effort was undertaken by the kerosene-heater industry in which the Department of Energy DOE 2.1A computerized thermal-load model and a 2-compartment mass-balance model were used sequentially to estimate pollutant levels in the heater room and in the rest of the house. The Health Sciences' staff has modeled pollutants using a steady-state model, and has used a dynamic 2-compartment model to a limited degree for comparative purposes.

The modeling of indoor-pollutant concentrations produced by kerosene heaters is complicated by the large number of factors that can vary between different heater users and different residences. Many of these factors and their contribution to the final pollutant concentration in a home are depicted in Figure 16. To simplify the modeling, Health Sciences "fixed" several of these parameters as shown in Figure 17.

Dynamic Modeling vs Steady-State Modeling

During the burning time of a heater, a dynamic combustion process occurs. Pollutants initially increase in concentration, eventually rising to a level closely approaching a steady-state concentration, then decrease after the heater is turned off, as the pollutants are purged by outside air infiltration.

Of primary concern to the staff is the pollutant concentration and duration of exposure at or near the maximum pollutant levels generated during this process. To elucidate this phenomenon, Health Sciences modeled dynamic profiles for open, semi-open (door ajar), and closed rooms. Table 3 presents a comparison of dynamic modeling vis-a-vis steady-state modeling for a comparably representative burn of a small (heat-output size) blue-flame heater. Overall, an 8-hour burn typically leads to a 5-hour to 7-hour exposure near the observed peak level, which is also 98% of the steady-state concentration. The Health Sciences' staff concludes that dynamic modeling will result in exposure estimates of approximately 80% to 95% of the exposure estimated by steady-state modeling.

Dynamic Pollutant Modeling for Residences

Using heater-emission rates, pollutant levels in a house were determined mathematically using equations published most recently by the National Academy of Sciences. Figures 18 and 19 graphically present the estimated hours of exposure, under different ventilation conditions, to concentrations of CO and NO_2 during, and for 3 hours after, an 8-hour burn of a small blue-flame heater with pollutant-emission rates typical of most heaters of this size and type. By way of explanation, Figure 18 shows that, with the door of the heater room fully open, all 11 hours of consumer exposure would be within the 0-5 ppm range for CO. On the other hand, if the door of the heater room were opened only 2 inches (door ajar), about 2½ hours of exposure to 0-5 ppm of CO would occur, with almost 8 hours of exposure to 6-10 ppm of CO. By further comparison, if the heater is operated in a room with the door closed, there is less exposure to the lower CO-concentration ranges, with well over 6 hours of exposure in the 16-20 ppm range. Figures 20 and 21 present corresponding data for CO exposure and NO_2 exposure respectively, derived for a typical medium-sized white-flame heater.

The range of room sizes which are modeled are representative of rooms in which heaters reportedly are used, as reflected in both the NKHA and Kero-Sun user surveys. According to these surveys, the door-ajar and open-house predictions appear to apply to 89% to 93% of the users; 7% to 11% of the users reported use of the heaters in a closed room.

Field Testing

Preliminary home monitoring data were obtained from two studies: an industry-sponsored study, performed by Weston Associates, that monitored a single occupied dwelling; and a study, sponsored in part by the CPSC, by the Pierce Foundation, Yale University, of approximately 130 homes with kerosene heaters and 190 homes without kerosene heaters. In addition, emission rates for 3 heaters used in the Weston study were obtained and "theoretical" pollutant concentrations modeled for comparison with "actual" levels measured. Figures 22 and 23 present comparisons of pollutant levels found in these two studies and the modeled data developed by the Health Sciences staff from the emission rates reported in the Weston study. A comparison of these data indicates that the pollutant levels measured in the homes of both studies exhibit similar ranges.

Nitrogen dioxide generally shows excellent agreement between measured and predicted values, and CO measurements are within 2½-fold of predicted values. The differences observed in sulfur dioxide (SO_2) concentrations between the Pierce Foundation study and Weston study may be due in part to differing sulfur content in the fuels used in each study. Fuel analyses of kerosene used in residences in the Pierce study showed a sulfur concentration range of 0.02% to 0.08%; the reported SO_2 pollutant concentrations in occupied dwellings during the study varied from near zero to about 0.4 ppm.

Hazard Assessment

Health Sciences has reviewed the literature concerning the toxicity of CO, carbon dioxide (CO_2), NO_2, and SO_2. The lowest concentrations at which health effects were observed for each of these pollutants in controlled human studies are presented in the following table.

POLLUTANT	EXPOSURE CONCENTRATION	OBSERVED EFFECT
CO	COHb concentration of 2.4% *	Electrocardiogram changes in some healthy adults; decrease in time to onset of pain in angina patients
CO_2	10000 ppm	Increased respiratory and gastrointestinal illness in submarine crews
NO_2	0.1 ppm	Increased airway resistance in asthmatics
SO_2	0.1 ppm	Increased airway resistance in asthmatics

* Blood carboxyhemoglobin (COHb) levels of 2.4% can be caused by exposures to 15 ppm CO for 8 hours, or to 25 ppm CO for 1 hour, with previous background exposure to 15 ppm for 4 hours.

Data on the levels of volatile organic pollutants and particulates emitted by kerosene heaters are not available and levels of formaldehyde were not found to be significantly increased in residences that used kerosene heaters.

Health Sciences concludes that, of the pollutants evaluated, NO_2 appears to be the major contributor to any health hazard posed by the use of kerosene heaters. The potential adverse effects to the general population from exposure to NO_2 include increased susceptibility to respiratory illness and possible lung damage, and increased airway resistance in asthmatics. Exposure to CO concentrations greater than 15 ppm may also occur from the use of kerosene heaters in closed rooms and may present a risk of anoxic stress to the heart of exposed individuals, especially those with angina.

Based on available toxicologic and exposure data from a typical use of kerosene heaters, as derived from the NKHA and Kero-Sun user surveys -- 8 hours/day for the heating season in an 1150-ft^2 house — Health Sciences concludes that small blue-flame heaters, when properly adjusted and used in an open room, produce concentrations of CO, CO_2, oxides of nitrogen and SO_2 at or below levels at which health effects have been noted for the general population.

In addition, the available data for the use of medium-sized blue-flame heaters and all sizes of white-flame heaters, properly adjusted and used in a room fully open to the rest of the house, do not lead Health Sciences to conclude that the general population is likely to experience adverse health effects, other than a possible increase in susceptibility to respiratory tract infection for some individuals. In addition, certain asthmatics and people with chronic lung diseases may experience mild breathing difficulties. A summary of the health effects associated with the use of kerosene heaters and the sensitive populations affected, is contained in Table 4.

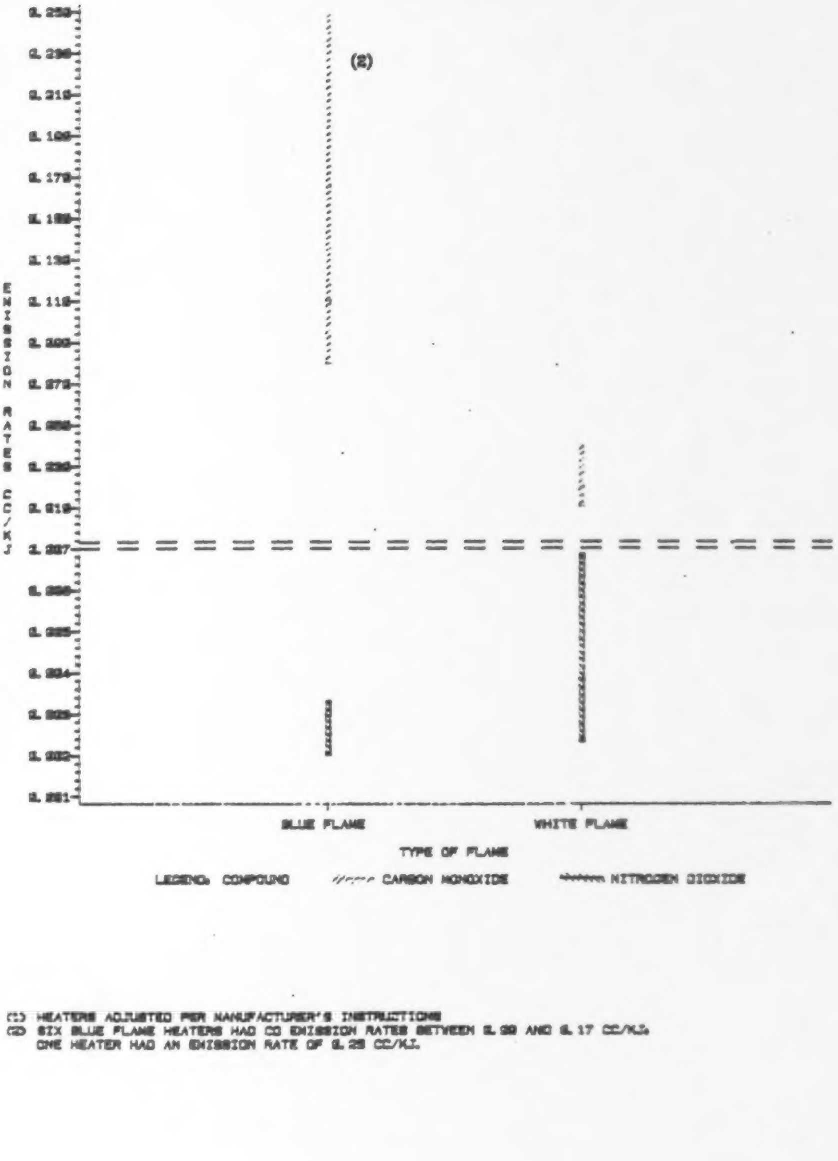
The possibility of occurrence of health effects, the severity of the health effects, and the size of the responding population group increase under the following conditions:

- Improper adjustment of the heater -- especially blue-flame heaters
- Use of high-BTUh-output heaters or wickless heaters
- Use of multiple heaters
- Use of heaters in a semi-open or closed room
- Use of heaters in a house with low outside air infiltration.

Any adverse respiratory effects produced by the use of these heaters may be exacerbated by the concomitant presence of SO_2 which is produced as a result of burning sulfur-containing fuels. The additive or synergistic effects of individual combustion pollutants as well as background pollutants were not taken into account in the evaluation of the hazard presented above. For a complete discussion of all aspects of heater emissions, emissions modeling, field-study data, and the health effects of combustion pollutants, refer to the materials, prepared by the Directorate for Health Sciences, at Tab D of this report.

FIGURE 15

KEROSENE HEATER EMISSION RATES(1)
FOR CARBON MONOXIDE AND NITROGEN DIOXIDE



(1) HEATERS ADJUSTED PER MANUFACTURER'S INSTRUCTIONS
(2) SIX BLUE FLAME HEATERS HAD CO EMISSION RATES BETWEEN 0.09 AND 0.17 CC/KJ.
ONE HEATER HAD AN EMISSION RATE OF 0.25 CC/KJ.

FIGURE 16

INTERRELATED FACTORS THAT DETERMINE INDOOR POLLUTANT CONCENTRATIONS FROM COMBUSTION APPLIANCES

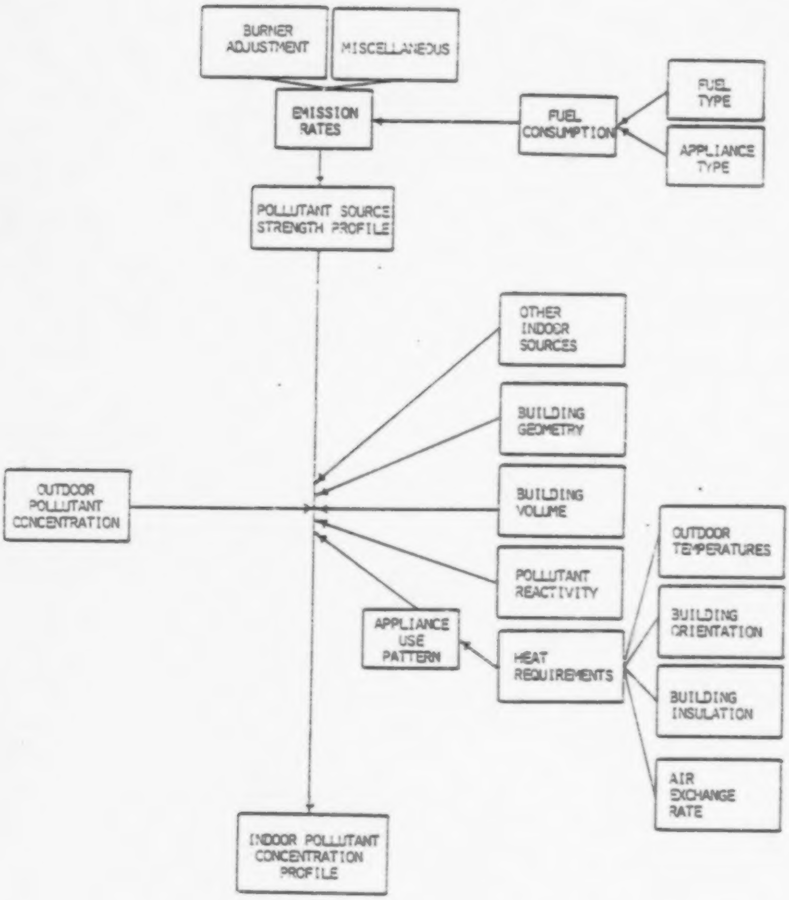

BURNER ADJUSTMENT
MISCELLANEOUS
EMISSION RATES
FUEL CONSUMPTION
FUEL TYPE
APPLIANCE TYPE
POLLUTANT SOURCE STRENGTH PROFILE
OTHER INDOOR SOURCES
BUILDING GEOMETRY
OUTDOOR POLLUTANT CONCENTRATION
BUILDING VOLUME
OUTDOOR TEMPERATURES
POLLUTANT REACTIVITY
BUILDING ORIENTATION
APPLIANCE USE PATTERN
HEAT REQUIREMENTS
BUILDING INSULATION
AIR EXCHANGE RATE
INDOOR POLLUTANT CONCENTRATION PROFILE

FIGURE 17

CPSC MODELING PARAMETERS

MODEL TYPES

Closed Room
doors/windows closed
room size scaled to maintain 70°F
no air exchange with adjacent room

Semi-Open Room
door open 2 inches
room size scaled to maintain 70°F
calculated mass air flow

Open House
interior doors open - rapid air mix
temperature not fixed to 70°F
calculated thermal balance

HEATERS

Small (n=6) - 6800 BTUh average
Medium (n=3) - 10400 BTUh average
Large (n=2) - 15600 BTUh average

HOUSE MODELS

Older House
0.8 ach - typical US value (NAS 1/)
0.49 BTU/ft^2-hr-°F heat requirement (Rand 2/)

Modern House*
.5 ach
0.37 BTU/ft^2-hr-°F heat requirement (DOE 3/)
0.32 BTU/ft^2-hr-°F heat requirement (AGA 4/)
0.21 BTU/ft^2-hr-°F heat requirement (NAHB 3/)

* 0.24 used by Health Sciences as representative of newer houses

TEMPERATURES

Outside - 0°F and 32°F
Inside (zone 2) - 50°F and 60°F

EMISSION RATES

calculated exclusively from averages of CPSC data

1/ Indoor Pollutants. National Academy of Sciences. 1981.

2/ Energy Use and Conservation in the Residential Sector: A Regional Analysis. Rand Corp. 1975.

3/ Monitored Low Energy Houses in North America and Europe. U.S. Department of Energy. 1982.

4/ Actual and Forcasted Conservation in the Residential Gas Space Heating Market Through 1990. American Gas Association. 1983.

Source: U.S. Consumer Product Safety Commission/Health Sciences

TABLE 3

COMBUSTION PRODUCTS FROM KEROSENE HEATERS:
Comparison of Dynamic Modeling vs Steady-State Modeling

CONDITIONS:
House Size - 1150 ft², single-story, ranch
Insulation Factor - low
Air Exchange Rate - .8
Heater Type - blue flame
Heater Size - 6800 BTUh
Outdoor Temperature - 0°F
Thermostat Temperature - 50°F
Hours of Burn - 8

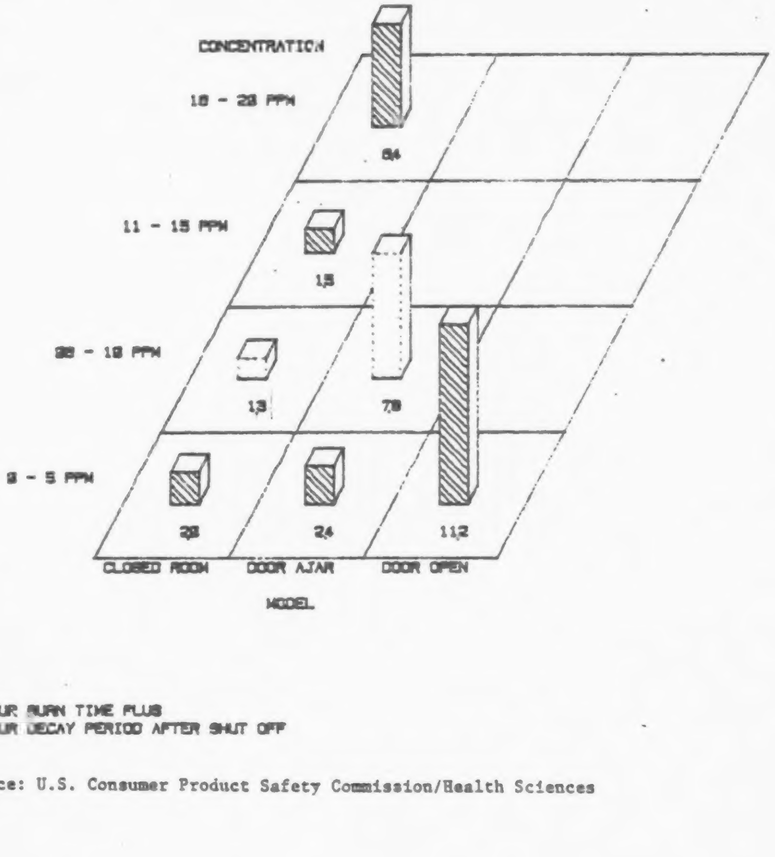
PREDICTED EXPOSURE CONCENTRATIONS
DURING HEATER USE

Pollutants	Door Open		Door Ajar		Door Closed	
	Dynamic	SS	Dynamic	SS	Dynamic	SS
CO, ppm	4.18	4.66	9.02	9.18	19.54	19.70
NO_2, ppm	0.06	0.07	0.12	0.13	0.23	0.25
CO_2, ppm	0.13	0.15	0.31	0.30	0.63	0.65

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 18

PREDICTED HOURS* OF EXPOSURE (PPM) TO CO
FROM TYPICAL SMALL (6800 BTUH) BLUE-FLAME KEROSENE HEATER

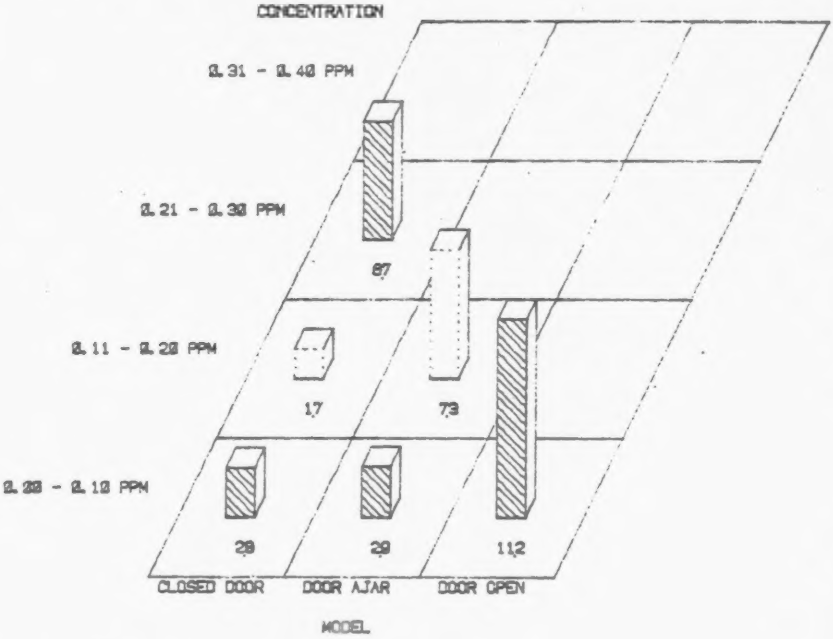


* 8 HOUR BURN TIME PLUS
3 HOUR DECAY PERIOD AFTER SHUT OFF

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 19

PREDICTED HOURS* OF EXPOSURE (PPM) TO NO2
FROM TYPICAL SMALL (6600 BTUH) BLUE-FLAME KEROSENE HEATER

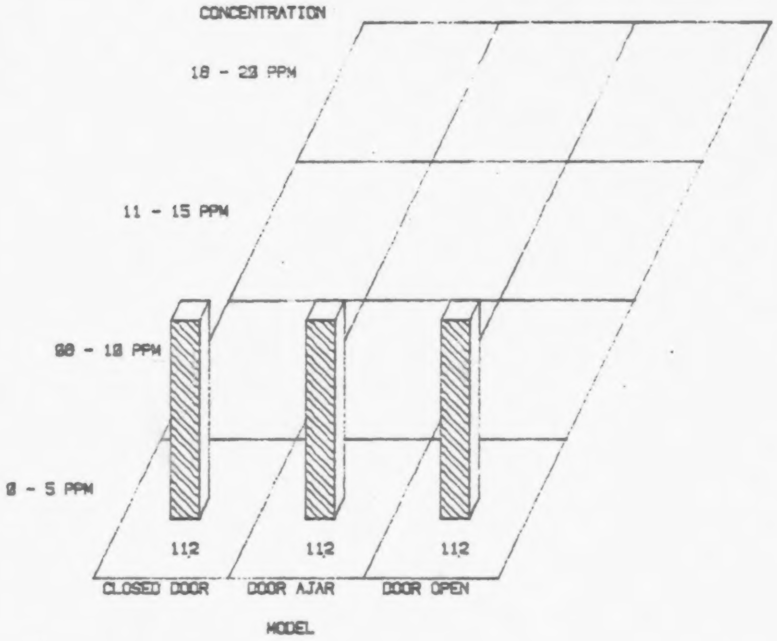


* 8 HOUR BURN TIME PLUS
3 HOUR DECAY PERIOD AFTER SHUT OFF

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 20

PREDICTED HOURS* OF EXPOSURE (PPM) TO CO FROM TYPICAL MEDIUM (10400 BTUH) WHITE-FLAME KEROSENE HEATER

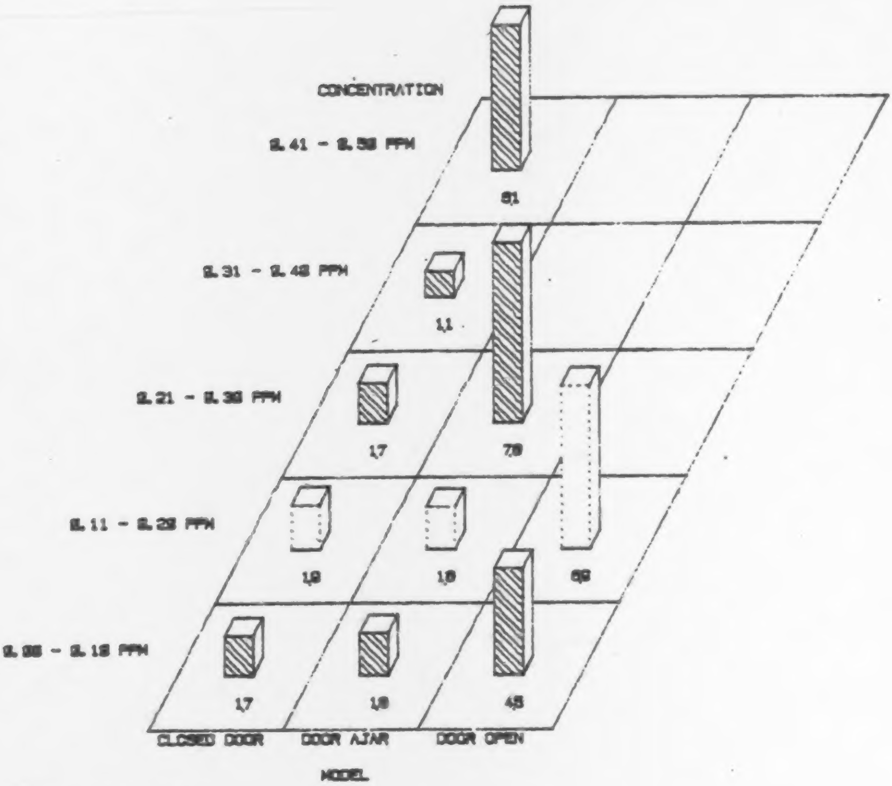


* 8 HOUR BURN TIME PLUS
3 HOUR DECAY PERIOD AFTER SHUT OFF

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 21

PREDICTED HOURS* OF EXPOSURE (PPM) TO NO2
FROM TYPICAL MEDIUM (10400 BTUH) WHITE-FLAME KEROSENE HEATER

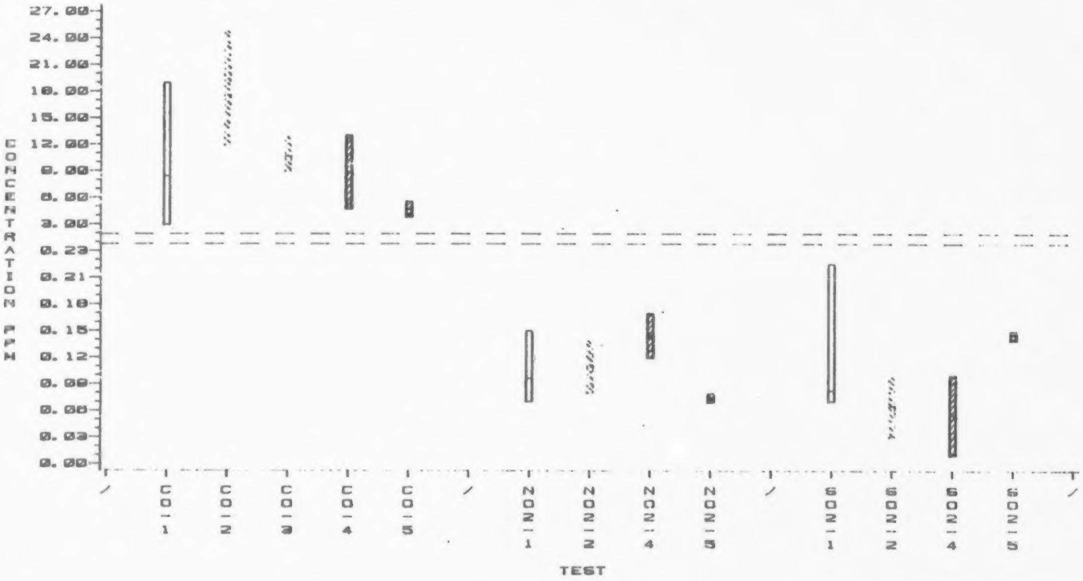


* 8 HOUR BURN TIME PLUS
3 HOUR DECAY PERIOD AFTER SHUT OFF

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 22

COMPARISON OF RANGES OF MAXIMUM OR NEAR STEADY-STATE POLLUTANT CONCENTRATIONS PREDICTED OR OBSERVED IN VARIOUS STUDIES WITH 9600 BTUH RADIANT HEATERS

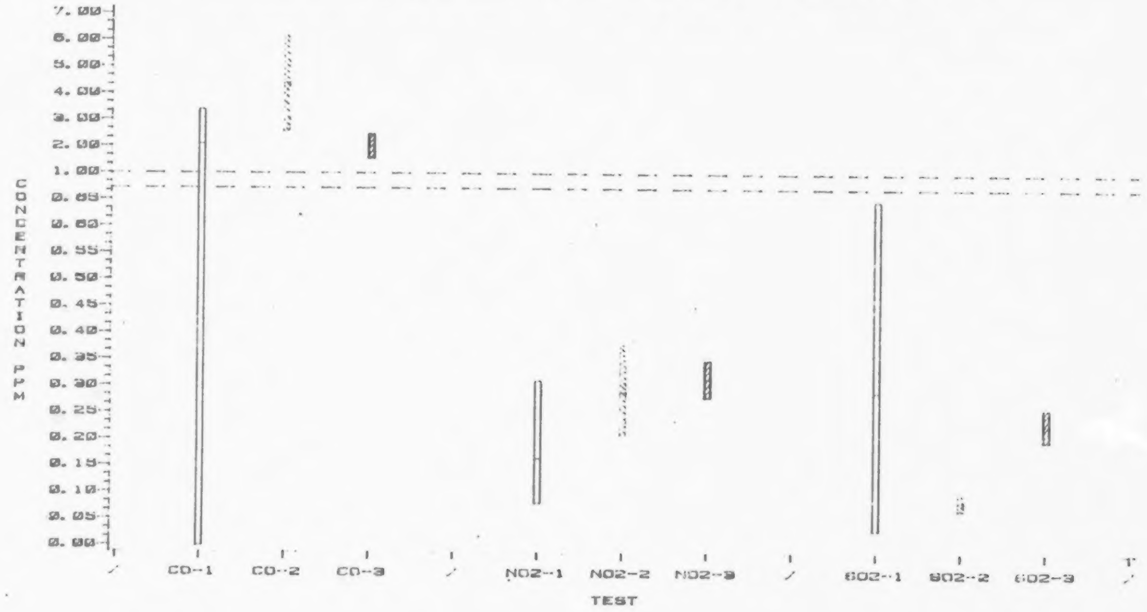


LEGEND. 1-PIERCE FOUNDATION - ADJUSTED TO WESTON-SIZED HOUSE (1100 SQ. FT.) - ————
[illegible]
[illegible]
4-WESTON MODELED - HOMEOWNER'S HEATER MODELED TO WESTON HOUSE (9600 BTUH) - ////////
5-WESTON MODELED - NEW HEATER MODELED TO WESTON HOUSE (9600 BTUH) - ////////

Source: U.S. Consumer Product Safety Commission/Health Sciences

FIGURE 23

COMPARISON OF RANGES OF MAXIMUM OR NEAR STEADY-STATE POLLUTANT CONCENTRATIONS PREDICTED OR OBSERVED IN VARIOUS STUDIES WITH 10400 BTUH CONVECTIVE HEATERS



LEGEND. 1-PIERCE FOUNDATION - ADJUSTED TO WESTON-SIZED HOUSE (1160 SQ. FT.) - ____
2-WESTON MODELED - HOMEOWNER'S HEATER MODELED TO WESTON HOUSE (10400 BTUH) - ////////

Source: U.S. Consumer Product Safety Commission/Health Sciences

TABLE 4

POSSIBLE HEALTH EFFECTS ASSOCIATED WITH THE USE OF KEROSENE SPACE HEATERS
BASED ON POLLUTANT CONCENTRATIONS PREDICTED FROM THE CPSC TESTING AND MODELING

HEATER TYPE, SIZE, AND USE CONDITION	POLLUTANT AND CONCENTRATION	POTENTIAL HEALTH EFFECTS*
SMALL BLUE-FLAME HEATERS, properly adjusted, used in an open room	NO_2: <0.10 CO: <10 ppm SO_2: **	Below reported effect levels. Adverse health effects not expected in most individuals.
MEDIUM BLUE*** AND ALL WHITE-FLAME HEATERS, properly adjusted, used in an open room SMALL BLUE-FLAME HEATERS, properly adjusted, used in a semi-open (door ajar) room	NO_2: <0.25 ppm CO: <15 ppm SO_2: **	NO_2: For the general population, a possible increase in susceptibility to respiratory tract infection; in certain asthmatics and persons with chronic lung disease, mild breathing difficulties. CO: Below reported health-effect levels.
ALL BLUE*** AND ALL WHITE-FLAME HEATERS, properly adjusted, used in a semi-open room; WICKLESS, used in an open room	NO_2: ≤ 0.4 ppm CO: ≤ 15 ppm SO_2: **	NO_2: For the general population, increased potential for respiratory-tract infections; for asthmatics and persons with chronic lung disease, increased potential for respiratory difficulties. CO: Below reported health-effect levels.
ALL HEATERS, used in a closed room	NO_2: >0.4 ppm CO: some exceed 15 ppm SO_2: **	NO_2: More of the exposed population affected; increases in the severity of any effects occuring at lower levels; increased possibility of cellular and structural damage of the lungs. CO: For persons with cardiovascular disease and for some healthy individuals, concentration dependent anoxic stress on the heart.

---

* The presence of SO_2 at concentrations of 0.1 ppm or above would be expected to exacerbate any predicted respiratory effects.

** The SO_2 levels ranged from 0.07 to 0.1 ppm in the Weston study, and from 0.03 to 0.65 ppm in the Pierce Foundation study; at this time the levels of SO_2 cannot be correlated with heater type, size or use conditions.

*** One high emitting blue-flame heater emitted CO in excess of 15 ppm, but this unit's emission level does not appear to meet UL standards.

INDOOR AIR QUALITY
FUEL - FIRED APPLIANCES

UNVENTED GAS SPACE HEATERS:
A PRELIMINARY REPORT

JULY 1983

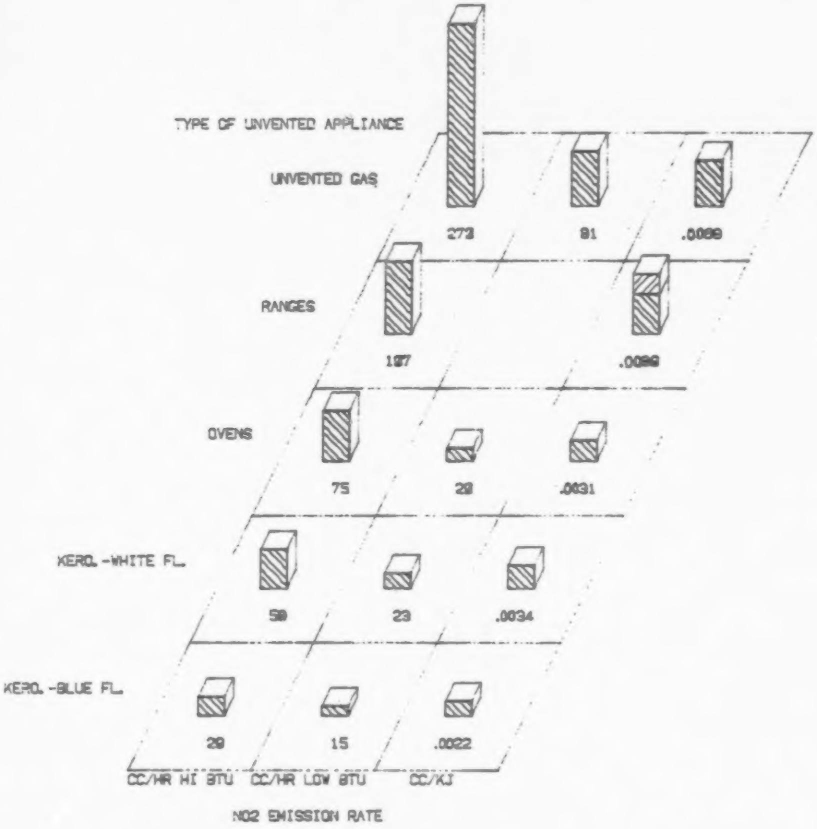
Chemical Hazards Program
U.S. Consumer Product Safety Commission
Directorate for Health Sciences
Washington, D.C. 20207

SUMMARY TABLES

TABLE 1

COMPARISON OF NO2 EMISSION RATES FOR PROPERLY ADJUSTED UNVENTED APPLIANCES

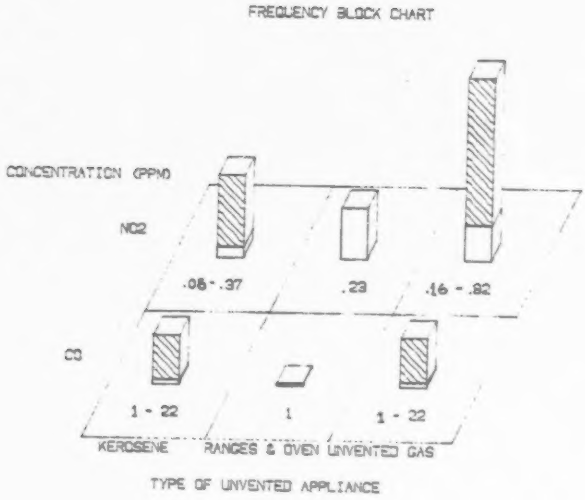
FREQUENCY BLOCK CHART



- EMISSION RATE IN CC/KJ IS MEASURE OF POLLUTANT OUTPUT PER UNIT OF HEAT OUTPUT
- EMISSION RATE IN CC/HR FACTORS IN THE BTU OUTPUT OF HEATER AND IS MEASURE OF TOTAL POLLUTANT OUTPUT OF APPLIANCE OVER TIME
- SCALE USED FOR EMISSION RATES IN CC/KJ IS NOT THE SAME AS THAT USED FOR CC/HR.

TABLE 2

PREDICTED POLLUTANT LEVELS IN AN 1150 SQ. FT. HOUSE



RATE FOR KEROSENE BASED ON RANGE OF CPSC MODELED LEVELS FOR WELL-TUNED KEROSENE HEATERS.

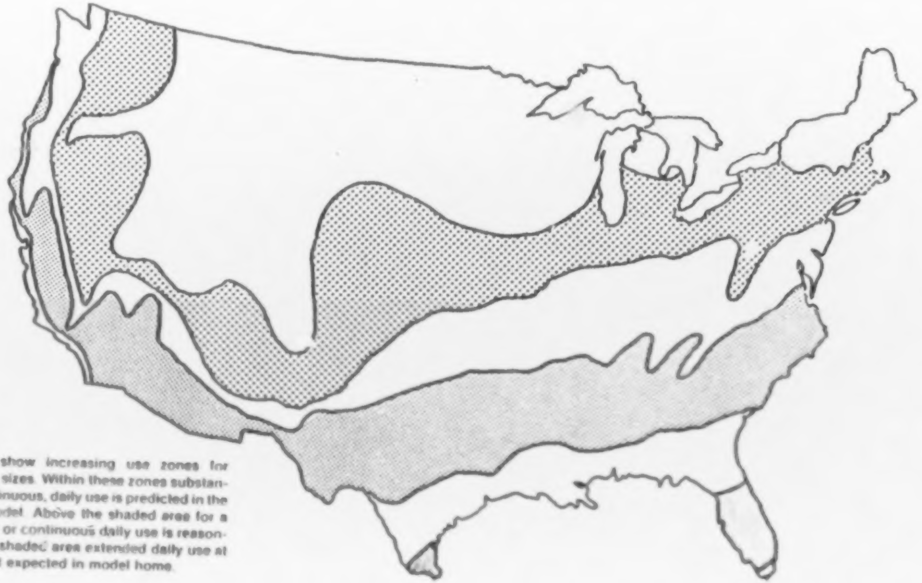
RATE FOR RANGES & OVENS BASED ON AMERICAN GAS ASSOCIATION STUDY OF 18 RANGES & OVENS ASSUMING 1 1/2 HRS. OF OVEN OPERATION AND 2 HRS. USE OF 2 BURNERS MODELED AT .5 AIR CHANGES PER HR.

RATE FOR UNVENTED GAS BASED ON RANGE OF CPSC MODELED LEVELS FOR WELL-TUNED UNVENTED GAS HEATERS.

FIGURE 1

PREDICTED REGIONAL UTILIZATION OF GAS HEATERS BY SIZE

SOURCE OF DATA: CLIMATIC ATLAS OF THE U.S., U.S. DEPT. OF COMMERCE



Shaded areas show increasing use zones for heaters of three sizes. Within these zones substantial, but not continuous, daily use is predicted in the CPSC home model. Above the shaded area for a heater extended or continuous daily use is reasonable. Below the shaded area extended daily use at full output is not expected in model home.

Code
▬ 9,000 BTU/h
▨ 20,000 BTU/h
▦ 30,000 BTU/h

TABLE I

PROJECTED POLLUTANT LEVELS FROM
UNVENTED GAS SPACE HEATERS
UNDER DIFFERENT MODELS[a]

	Well-tuned heaters				Mal-tuned	
	12A[b]	16B	30C[c]	30A[c]	30A[c] Surplus fuel	30A[c,e] Surplus primary air
				CO_2 (%)		
closed room	0.40-0.76	0.40-0.75	-	-	-	-
semi-open room	0.25-0.35	0.31-0.49	-	-	-	-
open room	0.14-0.22	0.25-0.31	0.46-0.74	0.46-0.74	0.46-0.74	0.46-0.74
				CO (ppm)		
closed room	4.0-7.6	23.4-43.6	-	-	-	-
semi-open room	2.5-3.5	18.1-28.5	-	-	-	-
open room	1.4-2.2	14.2-22.7	1.7-2.7	1.5-2.4	5.2-8.4	87.9-140.4
				NO (ppm)		
closed room	2.75-5.25	2.34-4.42	-	-	-	-
semi-open room	1.76-2.44	1.85-2.90	-	-	-	-
open room	0.97-1.55	1.44-2.39	3.82-6.10	2.85-4.56	d	
				NO_2 (ppm)		
closed room	0.47-0.88	0.98-1.83	-	-	-	-
semi-open room	0.31-0.41	0.80-1.12	-	-	-	-
open room	0.16-0.22	0.59-0.82	0.46-0.63	0.46-0.63	0.56-0.77	1.25-1.72

a: The range of pollutants given in each column refers to the highest and lowest values predicted under up to four model scenarios reflecting different temperature conditions and home heating load assumptions; for the closed room and semi-open room calculations a different room size is associated with each set of model conditions so that a 70°F heater room temperature is maintained.

b: Calculations for heater 12A were done on the basis of its measured fuel consumption of 9050 BTU/h, other heaters rated outputs were closer to their fuel consumption rates.

c: closed and semi-open room models are not felt to be appropriate for most home uses of a 30,000 BTU/h heater

d: none detectable in LBL test

e: This heater generated 1.3 ppm of formaldehyde with surplus primary air only; other heaters generated less than 0.1 ppm in field tests.

TABLE II

Predicted and Measured Steady State Levels of Oxygen and Pollutants Generated by Heaters in a 1150 ft^2 House

Heater	Air Changes Per Hour	Short Term Emission Rates Carbon Monoxide (PPM)		Short Term Emission Rates Carbon Dioxide (%)		Long Term Emission Rates Carbon Monoxide (PPM)		Long Term Emission Rates Carbon Dioxide (%)	
		P[a]	M[b]	P	M	P	M	P	M
30 A (well-tuned)	0.37	7.7	5.1	1.0	1.0	5.0	5.1	1.0	1.0
30 A (well-tuned)	0.49	5.8	4.2	0.8	0.8	3.9	4.2	0.8	0.8
30 A (well-tuned)	1.1	2.7	1.6	0.4	0.4	1.6	1.6	0.4	0.9
30A maltuned[c]	0.45	40.5	9.5	0.9	0.9	9.2	9.5	0.9	0.9
30A maltuned[c]	0.57	32.0	12.8	0.7	0.7	12.0	12.8	0.7	0.7
30A maltuned[c]	0.70	26.0	2.8	0.5	0.6	3.1	2.8	0.5	0.6
30A maltuned[d]	0.76	78.0	92.4	0.5	0.5	94.9	92.4	0.5	0.5
30C (well-tuned)	0.36	3.5	4.5	1.1	1.1	3.8	4.5	1.1	1.1
16B (well-tuned)	0.46	21.9	20.3	0.4	0.5	19.1	20.3	0.4	0.5
12A (well-tuned)	0.39	13.4	3.1	0.4	0.3	4.4	3.1	0.4	0.3

[a] Predicted [b] Measured [c] Excess fuel [d] Excess air

TABLE II continued

Predicted and Measured Levels of Oxygen and Pollutants
Generated by Heaters in a 1150 ft^2 House

Heater	Air Changes Per Hour	Short Term Emission Rates				Long Term Emission Rates			
		Nitrogen Dioxide (PPM)		Oxygen (%)		Nitrogen Dioxide (PPM)		Oxygen (%)	
		P	M	P	M	P	M	P	M
30A (well-tuned)	0.37	2.0	1.5	19.0	19.1	1.5	1.5	19.5	19.1
30A (well-tuned)	0.49	1.7	1.1	19.5	19.4	1.1	1.1	19.3	19.4
30A (well-tuned)	1.1	0.9	0.4	20.3	20.3	0.4	0.4	20.3	20.3
30A maltuned[c]	0.45	1.3	0.8	19.1	19.2	0.8	0.8	19.2	19.2
30A maltuned[c]	0.57	1.1	0.8	19.7	19.5	0.8	0.8	19.8	19.5
30A maltuned[c]	0.70	0.9	0.5	19.9	19.9	0.4	0.5	19.8	19.9
30A maltuned[d]	0.76	0.9	1.4	20.2	20.0	1.4	1.4	20.0	20.0
30C (well-tuned)	0.36	1.0	1.0	19.1	20.0	1.2	1.0	18.9	20.0
16B (well-tuned)	0.46	1.0	0.9	19.5	20.2	0.8	0.9	20.1	20.2
12A (well-tuned)	0.39	0.8	0.4	20.2	20.7	0.4	0.4	20.5	20.7

[a] Predicted [b] Measured [c] Excess fuel [d] Excess air

TABLE III

HEALTH EFFECTS OF CARBON DIOXIDE

Exposure Concentration and Duration	Species	Exposure Method	Effects	Source
4%, 2 wks	Human	Chamber	No psychomotor impairment; no decrement in complex task performance by healthy young subjects	Storm et al, 1974
3.9%, 5 days 11 days 2.7%, 30 days	Human	Chamber	Increased arterial and cerebrospinal fluid bicarbonate; decreased pH, some cardiac abnormalities; headaches	Sinclair et al, 1969
3%, 5 days	Human	Space Cabin Simulator	No changes in ammonia or titratable acidity; no changes in serum electrolytes, blood sugar serum creatinine, or liver function; no significant changes in exercise or psychomotor studies	Glatte et al, 1967
1.5%, 42 days 0.85%-1.2% 42-91 days	Human	Chamber* Submarine	Increases in respiratory minute volume, tidal volume, physiological dead space; decrease in vital capacity; respiratory acidosis, increase in pCO_2, decrease in pH; decrease of plasma chloride, red cell sodium increase, potassium decrease; decrease in plasma calcium metabolism, urine calcium, urine magnesium, increase in red cell calcium; in the submarine study a decrease in respiratory and gastrointestinal disease was noted with decreasing CO_2 (and other pollutants).	Schaefer, 1979

* Similar effects were noted in subjects in both the chamber exposure and submarine exposure.

TABLE III

HEALTH EFFECTS OF CARBON DIOXIDE (cont'd)

Exposure Concentration and Duration	Species	Exposure Method	Effects	Source
1%, 2%, days	Human	Chamber	Increase in blood pH, pCO_2 in blood and aveolar air, decrease in ability to perform strenous exercise	Zharov et al, 1963
1.5%, 6 wks	Guinea pigs	Chamber	Kidney calcification after 3 wks exposure, persisted after 6 wks recovery in air	Schaefer et al, 1963
1.0%, 6 wks	Guinea pigs	Chamber	Proliferation of type II pneumocytes	Douglas et al, 1969
1.0%, 6 wks	Guinea pigs	Chamber	Kidney calcification after 3 wks	Schaefer et al, 1979
0.5%, 8 wks	Guinea pigs	Chamber	Reversible kidney calcification, no lung ultrastructure changes	Schaefer et al, 1979

TABLE IV

HEALTH EFFECTS OF CARBON MONOXIDE

COHb	ppm	Exposure	Species	Effect	Reference
2.0%	50	Mouth piece	Human (Angina patients (N=15))	Decrease time to pain during exercise	Aronow, 1981**
2.4%	15	Chamber 48 hrs	Human (Healthy young men (N=30))	4/30 changes in EKG (p-wave); abnormal EKG at 36 hours, 1/30	Davies & Smith, 1980
2.7%	50	Mouth piece	Human (Angina patients (N=10))	Decrease time to pain during exercise	Aronow & Isbell, 1972**
2.9%	50	Mouth piece	Human (Angina patients (N=10))	Decrease in time to onset of pain	Anderson et al, 1973
3.95%	100	1 hr	Humans (N=10)	Mean exercise time on treadmill significantly reduced	Aronow & Cassidy, 1975**
2.6-5.5%	50-100	6 weeks intermittent & continuous	Dogs (N=12)	Abnormal EKG changes in right ventricular & arterial pressures	Lindenberg et al, 1962
7-12%*	100	continuously for 6 wks	Dogs (N=46)	Abnormal EKG's, heart dilation, myocardial thinning, some showed myocardial scarring degeneration	Preziosi et al, 1970

* Lower levels than would be expected from the exposure duration and level.

** An EPA peer review committee has questioned whether the "standard procedures" for a "double blind" study were violated.

TABLE IV

HEALTH EFFECTS OF CARBON MONOXIDE (cont'd)

COHb	ppm	Exposure	Species/Group	Effect	Reference
17%	180	continuously for 2 wks	Rabbits (N=16)	myocardial degeneration	Kjeldsen et al, 1974
20%	100	5.75 hrs/day 11 weeks	Dogs (N=4-6)	Abnormal EKG, increased heart size, myocardial degeneration, necrosis	Lewey & Drabkin, 1964 Erich et al, 1944
20.6%	250	Continuous 2 weeks	Monkey (N=20)	Cardiac pathology, widening of subendothelial spaces of coronary arteries	Thomsen, 1974

TABLE V

HEALTH EFFECTS OF NITROGEN DIOXIDE

Exposure Level	Duration	Species	Health Effect	REFERENCE
0.1 ppm	1 hour	Humans (mild asmathics)	Increased air way resistance in 13/20 patients	Orehek et al, 1976
0.12 ppm (or more)	30 min	Humans	Pharyngeal dryness, roughness and bronchoconstriction reported by some volunteers; odor perception	Henscheler et al, 1960 (as cited by NAS)
0.14 ppm + 1.1 ppm NO	68 months	Dogs	Emphysema-like lesions	Gillespie et al, 1980
0.25 ppm	4 hrs/day 6 days	Rabbits	Collagen damage in lungs persisting for 7 days after exposure	Mueller and Hitchcock, 1969
0.5 ppm	6 hrs/day 3 months	Mice	Emphysema-like lesions	Blair et al, 1969
0.8 ppm	990 days	Rats	Elevated respiratory infection rates (lifetime) and minimal bronchiolar hypertrophy	Freeman et al, 1966
5.0 ppm	2 months	Monkeys	tachypnea, decreased tidal volume, normal minute volume	Henry et al, 1973 (as cited in NAS)

TABLE V

HEALTH EFFECTS OF NITROGEN DIOXIDE (cont'd)

DOSE	EXPOSURE	SPECIES	EFFECT	REFERENCE
0.05 ppm + 0.1 ppm 1 hr/day	14 days	Mice	6.7% increased mortality after bacterial inhalation	Gardner, 1980
0.5 ppm	14 days	Mice	5.1% " " "	Gardner et al, 1979
0.5 ppm + 1.0 ppm 1 hr/day	14 days	Mice	12.4% " " "	Gardner, 1980
1.2 ppm + 2.5 ppm 1hr/day	14 days	Mice	13.7% " " "	Gardner, 1980
3.5 ppm	0.5 hours	Mice	10% " " "	Gardner et al, 1979
3.5 ppm	2 hours	Mice	18.7% " " "	Gardner et al, 1979
28 ppm	6 minutes	Mice	41.6% " " "	Gardner et al, 1979

TABLE VI

EPIDEMIOLOGY STUDIES

Exposure	Study Population (Number)	Effects	Source
Gas vs electric cooking	Children (5758, 4827)	Association of increased respiratory illness with use of gas stoves	Melia et al, 1977, 1979
Gas vs electric cooking kitchen (gas) 0.005-0.317 ppm NO_2 (elec) 0.006-0.188 ppm NO_2 bedroom (gas) 0.004-0.69 ppm NO_2 (elec) 0.003-0.037 ppm NO_2	Children (527)	An association of respiratory illness with bedroom NO_2 levels only	du V.Florey et al, 1979
Gas vs electric cooking	Children, Adults (441 families)	No effect	Keller et al, 1979
Gas vs electric cooking .02-.06 gas (peaks of .6-1 ppm) .01-.05 electric	Children (8120)	Significant association between history of serious respiratory illness before age 2 and use of gas stoves	Speizer et al, 1980

TABLE VI

EPIDEMIOLOGY STUDIES (cont'd)

Exposure	Study Population	Effects	Source
Gas vs electric cooking	Adults (1724)	Significant association between certain respiratory symptoms and gas (non-smoking men) or electricity (non-smoking women)	Comstock et al, 1981
Inversion	Greater London (City populations)	Concentrations of smoke and sulfur dioxide of0.75 mg/m^3 and 0.25 ppm, respectively, causes excess mortality.	Lawther, 1963
Inversion	New York City (City populations)	Significant increase in number of deaths associated with elevated air pollution (including SO_2, smoke) over a ten day period.	Greenberg et al, 1953
Air pollution	Children in Sheffield, England (City populations)	Association between respiratory illness and areas of higher pollution (including smoke, SO_2)	Lunn et al, 1967

TABLE VII

Lowest effective concentration of formaldehyde human and animal controlled studies.

mg/m^3	Length of Exposure	Species	Effect	Reference
0.01	5 min	Human	Eye irritation	Schuck *et al.* (1966)
0.06-0.07	Minutes	Human	Odor threshold	Wahren (1980) Melekhina (1964) Feldman and Bonashevskaya (1971)
0.08	Minutes	Human	Optical chronaxy threshold	Melekhina (1964)
0.1	1.5 months	Rabbit	Changes in evoked potential of optic nerve	Bokina *et al.* (1976)
0.1	Minutes	Human	Threshold to affect the functional state of cerebral cortex	Melekhina (1964)
0.24	1 h	Human	Eye, nose, and throat irritation	Rader (1974)
0.3	5 h	Human	Dryness of nose and throat, decrease in mucous flow rate	Anderson (1979)
0.4	1 h	Guinea pig	Increased airway flow resistance, decreased compliance	Amdur (1959)
0.67	10 min	Rat	Reduction in respiratory rate	Kane and Alarie (1977)
1.0	3 months	Rat	Histological and histochemical changes in cerebral amygdaloid complex	Bonashevskaya (1973)
1.0	1 min	Human	Altered functional state of cerebral cortex	Feldman and Bonashevskaya (1971)
1.0	90 days	Rat	Peribronchial and Perivascular hyperemia, lympholistiocytic proliferation in lung, focal hyperplasia and RE system activation in cerebral cortex	Feldman and Bonashevskaya (1971)
1.0	10 min	Human	Irritation of upper tract and eyes, accelerated breathing, EEG changes, such as alpha rhythm enhancement, changes of automatic nervous system	Sgibnev (1968)
1.0	10 months over 2 generations	Rat	Morphological changes in upper respiratory tract, decreased liver weight	Misiakiewicz *et al.* (1977)
1.0	Continuous beginning 10-15 days before mating	Rat	Increase in size and number of extramedullary hematopoietic centers, increased epithelial proliferation of common bile duct, increased abnormalities of renal epithelium	Gofmekler *et al.* (1968)

TABLE VII (Continued)

mg/m³	Length of Exposure	Species	Effect	Reference
1.7	1 min	Human	Eye sensitivity to light lowered in unacclimated group	Melekhina (1964)
2.0	Continuous or intermittent	Guinea Pig, rat	Sensitization (inhalation), leucocytosis, and change in blood cholinesterase	Ostapovich (1975)
2.4	6 h/day, 5 day/week for 18 months	Rat	Epithelial hyperplasia, squamous cell metaplasia of nasal turbinates, rhinitis	Swenberg *et al.* (1980)
4.6	90 days continuous	Rat, dog, rabbit, monkey, guinea pig	Death in 1/15 rats; some inflammation of lungs in all species	Coon *et al.* (1970)
5.0	4 h/day on days 1–19 of gestation	Rat	Increase in the threshold of neuromuscular excitability, increase in peripheral white blood cells, decreased hemoglobin and rectal temperature in pregnant animals	Sheveleva (1971)
5.0	1 min	Human	[illegible] without respiratory protection	Wiley (1908)
7 and 18	6 h/day, 5 day/week for 24 months	Rat, mice	Carcinogenic and other pathological changes in the nose (see text)	CIIT (1982)
19	10 h	Mouse, rabbit, guinea pig	5/7 mice, 3/5 rabbits, 8/20 guinea pigs dead; closed eyes, slow deep respiration convulsions	Salem and Cullumbine (1960)
50	1 h/day, 3 day/week for 35 weeks	Mouse	Upper respiratory tract inflammation, basal cell hyperplasia, epithelial stratification, bronchopneumonia	Horton *et al.* (1963)
588.0	4 h	Rat	L.C. 50 (approximate)	Nagornyi *et al.* (1979)
0.2 mg/L in water	Minutes	Human	Elicited allergic dermatitis response in a sensitized subject	Horsfall (1934)
3.7 g/L to 37 g/L for induction and 3.7 g/L for challenge as solution	Intermittent Patch	Human	Induced dermal sensitization in 4.5%–7.8% of healthy test subjects	Marzulli and Maibach (1974)

TABLE VIII

Human occupational and residential studies: ranges of formaldehyde concentrations giving adverse effects.

mg/m³	Effect	Type of Exposure	Reference
0.01-12	Nausea, eye, nose and throat irritation, headache, vomiting, stomach cramps	Residential	CPSC (1980)
0.02-5.0	Diarrhea, eye and upper-respiratory tract irritation, headache, nausea, vomiting	Residential	Woodbury (1979); Breysse (1977); Sardinas *et al.* (1979); Garry *et al.* (1980); Harris *et al.* (1981)
0.1-6.7	Burning of eye and nose, sneezing, coughing, and headaches, 3 out of 5 suffered from asthma or sinus problems	Occupational	Kerfoot and Mooney (1975)
0.36-3.3	Annoying odor, constant prickling of mucous membranes, disturbed sleep, thirst, heavy tearing	Occupational	Shipkowitz (1968)
0.15-0.55	Burning and stinging of eyes, nose and throat; headaches	Occupational	Bourne *et al.* (1959)
1.0	Loss of olfactory sense, increased upper respiratory disease, subatrophic and ciliostasis of nasal mucosa, increased absorptive function of nasal mucosa	Occupational (greater than 5 yr to less than 10 yr)	Yefremov (1970)
1.1-1.9	Itching eyes, dry and sore throats, disturbed sleep, unusual thirst upon awakening in the morning	Occupational	Morrill (1961)
1.1-3.3	Tearing of eyes, irritation of nose and throat	Occupational	Blejer *et al.* (1966)
?	Chronic airway obstruction, respiratory tract and eye irritation, small decrease in pulmonary function during workday and workweek	Occupational	Schoenberg and Mitchell (1975)
1.5-4.6	Menstrual disorders, pregnancy complications, low birth weight of offspring	Occupational	Shumilina (1971)
0.2 mg/L-30 g/L as solution	Allergic reactions: contact dermatitis, urticaria and asthma	Occupational and consumer	Horsfall (1934); Jordan *et al.* (1979); Rudner *et al.* (1975); Hendrick and Lane (1977); Alanko *et al.* (1977)

TABLE IX

Possible Health Effects Associated with Unvented Gas Spage Heater Use
Based on Pollutant Concentrations Predicted from CPSC Modeling

Heater Size, and Use Condition	Pollutant and Concentration	Potential Health Effects*
12,000 BTU, open room	NO_2: 0.25 ppm CO: 2.2 ppm HCHO: 0.1 ppm	NO_2: Possible increase in susceptibility to respiratory tract infection in some individuals, mild breathing difficulties in certain asthmatics and persons with chronic lung disease.
12,000 BTU, used in semi-open or closed room. Heaters larger than 12,000 BTU used in an open room.	NO_2: 0.4 ppm CO: generally less than 15 ppm	NO_2: Increases in the severity of effects occurring at lower levels; more of the exposed population affected; possibility of cellular and structural damage of the lungs.
Heaters larger than 12,000 BTU used in a semi-open or closed room. Maltuned heaters in an open room under certain conditions.	NO_2: 1 ppm CO: 15 ppm, may be as high as 140 ppm HCHO: **	NO_2: further increases in severiity of effects observed at lower levels in a dose related manner. Increased airway resistance in chronic bronchitics exposed to 1.6 ppm for 3 minutes. Longer exposure to these levels would be expected to produce more severe effects. CO: acute exposures above 50 ppm - 100 ppm likely to cause increased anoxic stress likely for all exposed individuals and headaches in some exposed individuals. Potential for myocardial degeneration in chronically exposed individuals. ***

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* The projected HCHO concentrations of 0.1 ppm or above would be expected to exacerbate any predicted respiratory effects.

** The projected HCHO levels for well tuned heaters were generally below 0.1 ppm. However one maltuned heater generated levels of 1.3 ppm. Such a level may cause moderate irritation of the respiratory tract and if exposure is prolonged, a cancer risk.

*** Concomitant exposure to the NO levels predicted for some of these heaters would be expected to exacerbate anoxic stress due to CO exposure.

SUMMARY DATA

INDOOR AIR QUALITY

VOLATILE ORGANIC CHEMICALS

DIRECTORATE FOR HEALTH SCIENCES

U.S. CONSUMER PRODUCT SAFETY COMMISSION

FIGURE 1

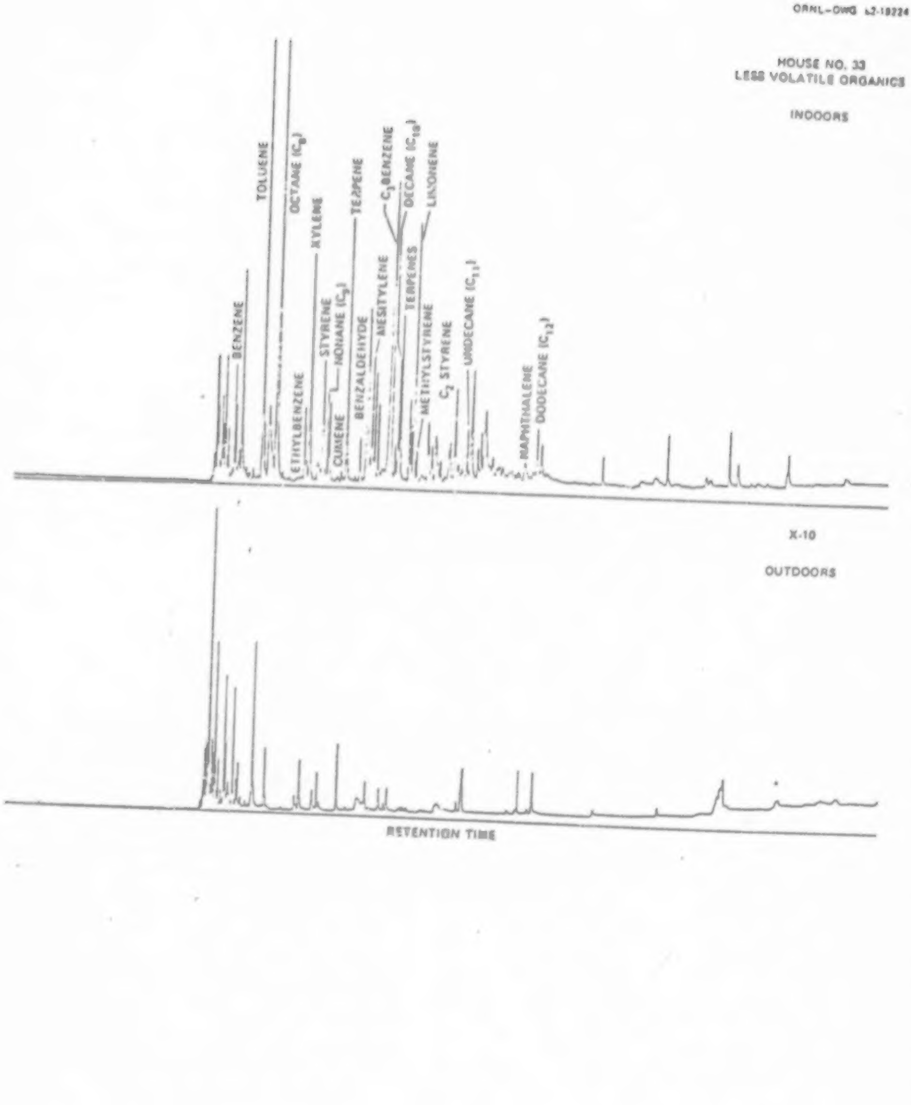
ORNL-DWG 82-19224
HOUSE NO. 33
LESS VOLATILE ORGANICS
INDOORS
BENZENE
TOLUENE
ETHYLBENZENE
OCTANE (C_8)
XYLENE
STYRENE
CUMENE
NONANE (C_9)
BENZALDEHYDE
TERPENE
MESITYLENE
C_3 BENZENE
DECANE (C_{10})
TERPENES
METHYLSTYRENE
LIMONENE
C_2 STYRENE
UNDECANE (C_{11})
NAPHTHALENE
DODECANE (C_{12})
X-10
OUTDOORS
RETENTION TIME

TABLE 1

Levels of selected organic chemicals.

Chemical	Winter			Summer		
	N	Mean ($\mu g/m^3$)	Standard Deviation	N	Mean ($\mu g/m^3$)	Standard Deviation
Toluene	17	27.2	15.6	85	61.7	96.1
Ethyl benzene	14	4.4	3.2	84	10.5	21.1
Xylene(m,p)	17	16.6	14.8	84	44.2	90.7
Nonane	14	10.6	25.4	82	6.4	6.8
Cumene	7	2.2	2.4	68	1.3	2.4
Benzaldehyde	11	22.3	44.1	24	51.7	70.4
Mesitylene	3	1.4	0.7	80	6.7	9.2
Decane	14	12.4	12.0	81	8.9	12.8
Limonene	13	10.3	7.9	77	20.8	32.1
Undecane	14	8.2	9.0	81	12.0	18.8
Napthalene	12	9.4	20.7	80	17.5	75.8
Dodecane	15	4.2	3.0	84	13.7	73.7
2-Methylnaphthalene	8	2.5	1.9	47	2.6	4.2
Tridecane	14	2.3	1.3	85	16.5	25.3
Tetradecane	15	3.2	1.3	85	7.5	10.2
Pentadecane	14	2.8	1.0	84	1.9	2.4
Hexadecane	4	3.7	1.6	81	3.8	4.7

TABLE 2

Health Effects of Organic Indoor Air Pollutants

Pollutant	Health Effects
1. Benzene	Human carcinogen. Benzene is associated with acute myelogenous leukemia, erythroleukemia and acute myelomonocytic luekemia. Chronic toxic effects on bone marrow leading to pancytopenia often with aplasia. Acute toxic effects are primarily on the central nervous system.
2. Toluene	Embryotoxic and teratogenic in mice. Inhalation exposure causes throat and eye irritations and central nervous system effects.
3. Ethylbenzene	Causes mucus membrane irritation in humans. Both inhalation and dermal exposure can cause an irritant response.
4. Xylene (m & p)	Embryotoxic; suspected teratogen in rats and mice; central nervous system depressant, and mucous membrane irritant.
5. Cumene	Irritant to mucous membrane, causes liver, lung and kidney damage.
6. Benzaldehyde	Irritant to respiratory system and eyes; chromosomal changes in *in vitro* test systems; sensitizer, and central nervous system depressant in humans and animals. Causes kidney and brain damage in animals.

[*] Health effects are based on information from the Registry of Toxic Effects of Chemical Substances (RTECS), from the Toxicology Data Bank (TDB), and a review of some articles obtained from Medline, Cancerline and Toxline.

TABLE 2 Cont.

Pollutant	Health Effects
7. Mesitylene	Mucous membrane irritant, central nervous system depressant.
8. Limonene	Skin irritant; sensitizer and a possible tumor promoter.
9. Naphthalene	Skin or mucous membrane irritant; vapors may cause headaches, loss of appetite, nausea, neuritis, kidney damage, may cause hemolytic effects.
10. 2-Methylnaphthalene	Adverse effects on liver function in rats. High concentration (800 mg/kg) can damage the upper respiratory tract.
11. Diethylphthalate	Causes chromosomal aberration in *in vitro* mammalian tests; fetotoxic and teratogenic in rodents.
12. Dodecane	Co-mutagen, co-carcinogen (tumor promotion); irritant; narcotic at high concentrations.
13. Tridecane	Irritant; narcotic at high concentrations; causes asphyxia.
14. Tetradecane	Co-mutagen, co-carcinogen (tumor promotion); irritant; narcotic at high concentrations.
15. Pentadecane	Irritant;
16. Hexadecane	Irritant (topical application to skin causes hyperkeratosis); causes asphyxia.

Mr. FUQUA. Thank you, and we will take those and make them available to the staff, those reports that you have.

Dr. Moschandreas.

Dr. MOSCHANDREAS. Mr. Chairman, my name is Demetrios Moschandreas. I am the research director of the Chemistry and Chemical Engineering Research Division of the IIT Research Institute. I welcome the opportunity to appear before you and to present my views on the status of current research and future requirements regarding the air quality of indoor environments.

My research efforts during the past several years have concentrated on the characteriziation of indoor air pollution and the measurement of physical and chemical factors that affect the quality of air inside residences and other nonindustrial environments.

In the past 2 years I have focused my research on the study of emission rates from unvented gas appliances and other sources. My conclusions on the present state of knowledge and my perception of the needs for future research are based on my own findings and continuous involvement with national and international forums, such as the National Academy of Sciences' Committee on Indoor Pollutants.

I would like to concentrate on emission rates. Emission rates from indoor pollution sources, such as unvented gas appliances, can be measured by two experimental techniques. In my current work I apply both methods with gas appliances. Preliminary results show that the two approaches burn a similar but not exactly the same emission rates.

The differences associated with these two techniques must be resolved before we continue making concusions. The differences may be attributed to the fuel use, the appliance itself, the experimental apparatus used, and other techniques integral of the method that is being applied.

The need for establishing an experimental design is apparent. Otherwise, we will have tremendous difficulties comparing our results.

Currently in my studies I measure emission rates for carbon monoxide, nitrogen dioxide, nitric oxide from range top burners, ovens, space heaters, clothes dryers vented indoors, and combinations of the above sources. It is my hope that we will continue measuring emission rates from other indoor sources.

In addition, we also measure in chamber experiments the chemical decay factors; that is, the zinc sources on various surfaces. Finally, we measure the efficiency of indoor air quality control devices.

Volatile organic compounds, a subject brought up previously by Dr. Preuss, and polynuclear aromatic hydrocarbons from sources that I have been testing in the past 2 years appear to be minimal. Yet, in a study performed recently by members of my team, we found that indoor levels of volatile organic compounds are markedly higher than corresponding outdoor levels.

We have identified about 300 volatile organic compounds at various levels. A statistical analysis to associate these compounds with various indoor sources, activities, and building factors did not prove fruitful.

Another area that we have been studying continuously in the past several years is wood burning, an increasingly used alternative fuel. Studies I have performed in the past show that under certain conditions wood burning activities result in increased concentrations of benzo-a-pyrene, which is carcinogenic.

We are currently studying wood burning activities in several residences that are controlled, staged experiments. It is our preliminary conclusion that when wood burning takes place under normal conditions, the indoor emissions are minimal. When the flow of the air is not as it is supposed to be, concentrations of particulate matter and polynuclear aromatic hydrocarbon increase very much.

One must put this findings in proper perspective. The issue is not if source A emits more than source B. Rather, the issue is whether its source or combination of sources lead to indoor concentrations that should cause concern.

This is not an easily resolved issue because, one, a demarcation line between healthful and unhealthful air in indoor environments has not been established; that is, we do not know the levels of concerns; and two, emission rates do not constitute the only factor that determines the final indoor concentration attributed to a source.

The source usage pattern, the condition of the source itself, the fuel used, and the indoor conditions, along with the building location and the air exchange rate are equally important factors. Consequently, a 1-to-1 source comparison is misleading.

The issue, therefore, I submit is broader. Presently, using anecdotal research, we have sufficient data to suspect a potential problem. In the future we must direct research efforts to attain two objectives: one, quantify the magnitude of indoor air quality problems; and two, when necessary, improve the air quality of indoor environments.

We must, therefore, respond to the following three questions: One, what is the indoor air quality of the U.S. housing stock; two, what are the adverse health effects associated with the indoor air quality; and three, what is the magnitude of indoor air quality potential problems and the associated risks?

A properly designed national survey air monitoring study will respond to the need to characterize indoor air quality. Such a study is extremely difficult. Difficulties include the choice of appropriate size sample, the choice of appropriate instrumentation.

Since such a study will be undertaken by many research groups, we must establish a quality assurance/quality control program. In addition to air quality parameters and variables, we must study energy variables and building parameters in this national survey study.

An essential element of such survey monitoring study is the activity of the occupants. A daily log is required. Scientists like myself, who will need the help of social scientists to obtain such information without violating the privacy of the public.

The output of such a study would be a statistical determination of indoor air quality. The scientific community will be able to state the indoor concentrations of air pollutants and their any given condition. Such information is necessary. Yet, it is not sufficient to estimate the magnitude of indoor air pollution problems.

In addition, we must assess the health effects associated with the observed concentrations and their frequency of occurrency. There are two possible avenues of assessing these effects. One is health studies and the other one is guideline based on best available knowledge.

Health studies in principle will provide the required information. In practice, such studies may require too much time. I am sure that others better qualified than I am in this field will suggest a research program for health studies. I support such a study.

I also would like to suggest that in the near future we should assess the health risks in indoor environments using the best available health information. To that extent, the World Health Organization recently held a workshop of 16 international indoor air quality experts. These scientists formulated a table indicating pollutant concentrations that should cause concern. I have taken the liberty to include this table in my written testimony for the record.

This table may not be the final set of health guidelines, but for the purposes of determining the magnitude of indoor air quality problems, it is a most important first step. I emphasize that these guidelines are transient in nature. Health standards implemented in the next few years will improve our current knowledge and will determine the health effects and therefore will establish indoor pollutant concentrations of concern.

The third element of the proposed program is a synthesis task. Equipped with information on the character of indoor air quality and the associated health effects and a number of auxiliary information sources, scientists will be ready to assess the magnitude of the indoor air quality problem and to suggest corrective measurements when needed.

Toward that end, specific research concerns must be resolved. They include the formulation of numerical models that simulate all indoor conditions, the application of risk analysis techniques, and the implementation of cost/benefit analyses.

During these synthesis tasks, several policy issues must be addressed. The issues that should be addressed include whether indoor air quality should be treated as a priority environmental concern. Is it a problem sufficiently severe to warrant public action?

Whether the Clean Air Act should be explicitly—should explicitly include indoor air quality; whether a mechanism to coordinate Federal research and other activities related to indoor air quality should be established.

If regulatory decisions are necessary, the policy issue is whether to establish indoor air quality standards or control the emission rates of the sources themselves.

If regulatory steps are required, a decision must be made on how to enforce these regulations without violating the privacy of the public.

Nonregulatory activities are preferred currently by those involved in indoor air quality research. It is up to the decisionmakers to determine the agency that will lead the education of the public.

In conclusion, I have suggested a rather involved and complex problem. Consequently, I would like to suggest that the research involved must be done expeditiously and comprehensively, and it must be done correctly the first time.

To that end, I propose that a panel of respected experts be brought together to oversee on a regular basis the program design, formulation, and study performance. As the program evolves, this panel will direct research efforts to resolve the issues in a most effective manner. I believe that our goals can be attained in the next few years.

Thank you.

[The prepared statement of Dr. Moschandreas follows:]

Testimony of

Demetrios J. Moschandreas

Research Director
Chemistry and Chemical Engineering Research Division
IIT RESEARCH INSTITUTE
Chicago, Illinois

On

INDOOR AIR QUALITY RESEARCH NEEDS

Before the

Joint Hearing of
Energy and Development Applications
and
Environment Subcommittee

August 2, 1983

IIT RESEARCH INSTITUTE

Mr. Chairman, my name is Demetrios Moschandreas. I am the Research Director of the Chemistry and Chemical Engineering Research Division of IIT Research Institute. I welcome the opportunity to appear before you and present my views on the status of current research and future requirements regarding the air quality of indoor environments.

Like any other research area, indoor air quality research issues fall into three broad categories: (1) issues that can be answered scientifically; (2) issues that can be answered scientifically in principle; and (3) issues that require scientific inputs but are not scientific.

In my opinion, characterization of the indoor environment falls in the first category, I assign health effects studies in the second category, and all policy issues related to indoor environments belong to the third category. I will focus my remarks on the characterization of indoor environments. I will briefly review my own research interests and findings and I will address my perceptions of research requirments in order to assure protection of the public welfare in indoor environments.

Characterization of indoor air quality is the stochastic determination of indoor pollutant concentrations as a function of emissions from indoor sources, indoor activities, energy conservation measures, climatic conditions, and efficiency of control devices.

My research efforts during the past seven years have concentrated on the characterization of indoor air pollution and the measurement of physical and chemical factors that affect the quality of air inside residences and other indoor nonindustrial environments. In the past two years, I have focused my research on the study of emission rates from unvented gas appliances and other sources. I will not attempt to furnish technical details of my work or my findings. I will, however, point out some of the difficulties involved. My conclusions on the present state of knowledge and my perception of the needs for future research are based on my own findings and continuous involvement with national and international workshops and conferences.

Emission rates from indoor pollution can be measured by two experimental techniques. In the first approach, the effluents of a source are directed to an air sampling port and the emission rate for a given pollutant is measured stoichiometrically. The second approach uses environmental chambers where the ambient indoor concentrations are measured along with the air change rate of the chamber, the fuel consumption, and other factors. A mass balance equation is employed to estimate the emission rate for each air constituent emitted by the source. In my current work I employ both methods with three gas appliances using the same fuel. Preliminary results show that the two approaches furnish similar but not exactly the same emission rates. The stoichiometric approach estimates emission rates which are frequently lower than the mass balance approach. This may be attributed to many factors including the time of estimating the emission rates. In the stoichiometric measurements one uses steady state levels; this is not necessarily the case in chamber measurements. The impact of temperature and relative humidity is also not clear. Finally, the mass balance model utilized assumes perfect mixing within the chamber; this may or may not be the case.

Additional difficulties include the composition of the fuel used. In my studies I control this quality by using the same fuel for all experiments; however, when one compares literature results, one must allow for some difference from this factor. In addition, we observe differences as a function of the appliance used. A mildly surprising but explainable result is that the emission rates appear to exhibit a slight dependence on the air exchange rate of the chamber. An unnecessary complexity in comparing the results relates to the units used. Transformations are easy, yet they often cause approximations which lead to differences that may be substantial on a relative basis. Finally, the experimental apparatus itself is of importance. In my studies I follow the ANSI recommended approach for estimating emission rates from unvented gas appliances; thus, we put on the burner a specially designed water pot which others do not. The need for establishing an experimental design is apparent. Currently, we measure emission rates of carbon monoxide, nitrogen dioxide, and nitric oxide from range top burners, ovens, space heaters, clothes dryers vented indoors, and combinations of the above sources. The emission rates of other sources will be measured in the near future.

The emission rates of volatile organic compounds and polynuclear aromatic hydrocarbons from the sources tested were found to be minimal. Yet, in a study performed recently by members of my team, we found that indoor levels of volatile organic compounds are markedly higher than corresponding outdoor levels. We have identified about 300 VOC's at various levels. A statistical analysis to associate these compounds with various indoor sources, activities, and building factors did not prove fruitful. Woodburning is increasingly used as an alternative fuel. Studies I have performed in the past show that under certain conditions, indoor benzo-α-pyrene concentrations increase. We are currently studying woodburning activities in several residences. Presently, we believe that under normal conditions, indoor emissions from woodburning facilities are minimal; however, if the flow of air is not as expected, concentrations of particulate matter and polynuclear aromatic concentrations increase.

One must put these findings in proper perspective. The issue is not if source A emits more than source B; rather the issue is whether each source or combination of sources, emitting at the measured rate, leads to indoor concentrations that should cause concern. This is not an easily resolved issue because: (1) a demarcation line between healthy and unhealthy air in indoor environments has not been established; that is, we do not know the levels of concern; and (2) emission rates do not constitute the only factor that determines the final indoor pollutant concentration attributed to a source; the source usage pattern, the condition of the source, the fuel used, the indoor environmental conditions, the building location, and air exchange rate are equally important factors. Consequently, a one-to-one source comparison is misleading because the source with the highest emission rate may be used infrequently and/or for short periods of time as opposed to a low emitting source which may be used for long periods of time.

The issue therefore is broader. Presently, using anecdotal research, we have sufficient data to suspect a potential problem. In the future we must direct research efforts to attain two objectives: (1) quantify the magnitude of the indoor air quality problems, and (2) when necessary, improve the air quality of indoor environments. We must respond to the following three questions: (1) what is the indoor air quality of the U.S. housing stock; (2) what are the adverse health effects associated with the indoor air quality;

and (3) what is the magnitude of the indoor air quality potential problem and associated risks.

A properly designed national survey air monitoring study will respond to the need to characterize indoor air quality. The complexities involved are many and must be addressed early in the study. Determination of an appropriate sample size that will represent a very large set of conditions is obviously a difficult task. Selection of proper instrumentation is another difficulty. The first generation of mobile laboratories used by Lawrence Berkeley Laboratories, my own research team, and others are too bulky, expensive, and not suitable for survey studies. We need instruments and instrument assemblies that are small in size, versatile, and do not require continuous attention. Such instrumentation must be developed for many pollutants, especially if we are interested, as I believe we are, in short term concentrations. In addition to air quality factors, energy variables and building parameters will be quantified during the national survey study. An essential element of such a survey monitoring study is the activity of the occupants. A daily log is required. Indoor air quality scientists will need help from social scientists to obtain the required information without imposing on the privacy of the public. The proposed national survey will be undertaken by many research groups, therefore, it is imperative to develop a sound experimental design and apply a detailed Quality Assurance/Quality Control program. A rather large data base will be generated. The required analysis will be complex and its interpretation difficult. An integral part of the experimental design must be the proposed analytical process. In parallel with the field component of the national survey, I propose we undertake a series of laboratory experiments to quantify factors that cause deterioration of the indoor air such as emission rates of various sources, factors that impact on the character of indoor air quality such as chemical decay rates, and factors that may improve the quality of indoor air such as the efficiency of control devices.

The output of such an undertaking will be a stochastic determination of indoor air quality; the scientific community will be able to state the indoor concentrations of air pollutants under any given set of conditions. This information is necessary but not sufficient to estimate the magnitude of the indoor air pollution problem. In addition, we must assess the health effects associated with the observed concentrations and their frequency of occurrence.

There are two possible avenues for assessing these effects: (1) health studies; and (2) guidelines based on best available knowledge. In principle, health studies provide the required information. In practice, such studies require time that may not be available. I am sure that others better qualified in the field will suggest a research program for health studies in conjunction with the national monitoring survey and I support such an undertaking. These health studies must isolate the component of adverse health effects attributed to exposure to air pollutants found in indoor environments. I am told that this health task is difficult and time consuming. I would like to suggest an alternative: for the near future, we should assess the health risks in indoor environments using the best available health information. The present data base may be incomplete, it may be subject to scientific debate, but I submit it must be used. Along these lines the World Health Organization recently held a workshop of 16 international indoor air quality experts. These scientists formulated a table indicating pollutant concentrations that should cause concern. I have taken the liberty to include this table in my written testimony for the record. This table may not be the final set of health guidelines, but for purposes of determining the magnitude of the indoor air quality problem, it is a most important first step. I emphasize that these guidelines are transient in nature. Health studies implemented in the next few years will improve our current knowledge, will determine the adverse health effects, and will establish indoor pollutant concentrations of concern.

The third element of the proposed program is a synthesis task: equipped with information on the character of indoor air quality and the associated health effects and a number of auxiliary information sources, scientists will be ready to assess the magnitude of the indoor air quality problem and to suggest corrective measurements when needed. Toward that end, specific research concerns must be resolved; they include the formulation of numerical models that simulate all indoor conditions, the application of risk analysis techniques, and the implementation of cost/benefit analyses. Several policy issues require resolution during this synthesis.

CONSENSUS OF LEVELS OF CONCERN FOR INDOOR AIR POLLUTANTS AT 1982 LEVELS OF KNOWLEDGE

Pollutant 1)	Range of concentrations Reported Indoors	Concentration of limited or no concern	Concentration of concern	Remarks
Tobacco Smoke (Passive)	0.1-1 $mg \cdot m^{-3}$ resp. particulate	-$\sim$ 0	- *	Japanese Stnd. 0.15 $mg \cdot m^{-3}$
NO_2	0.05-1 $mg \cdot m^{-3}$	< 0.19 $mg \cdot m^{-3}$	> 0.32 $mg \cdot m^{-3}$	according to WHO EHC 99.9%
CO	1-100 $mg \cdot m^{-3}$	< 11 $mg \cdot m^{-3}$ (2% COHb)	> 30 $mg \cdot m^{-3}$ (3% COHb)	cont. expo.
Radon and daughters	4-8000 $Bq \cdot m^{-3}$	$\sim$ 0	> 70 $Bq \cdot m^{-3}$	Swedish Stnd.
Formaldehyde	0.06-1.3 $mg \cdot m^{-3}$	< 0.06 $mg \cdot m^{-3}$	> 0.12 $mg \cdot m^{-3}$	Long & short term
SO_2	0.02-1 $mg \cdot m^{-3}$	< 0.5 $mg \cdot m^{-3}$	> 1.35 $mg \cdot m^{-3}$	SO_2, alone, short term 2)
CO_2	600-9000 $mg \cdot m^{-3}$	< 4500 $mg \cdot m^{-3}$	> 12000 $mg \cdot m^{-3}$	Japanese Stnd. 1800 $mg \cdot m^{-3}$
O_3	0.04-0.4 $mg \cdot m^{-3}$	< 0.12 $mg \cdot m^{-3}$	> 0.15 $mg \cdot m^{-3}$	WHO criteria document
Asbestos	< 1 fibre, cm^{-3}	$\sim$ 0	>.1 $fibre \cdot cm^{-3}$	For long term exposures
Mineral fibers	-	*)	*)	
Organics	-	*)	*)	

*) Because of the complex nature of these pollutants meaningful concentrations cannot be given

1) All gases are considered alone, without other contaminants

2) Only short term effects of SO_2 alone were considered, without particulates, or sulfates or NO_2 which may be present simultaneously and are then likely to be the limiting factor. For long term exposures, outdoor air quality standards or guidelines will provide a better margin of safety.

Indoor air quality scientists assert that the principal component of exposure to air pollutants is in the indoor environment. Consequently, the indoor air environment must be studied comprehensively and expeditiously. I have outlined a large complex research program. In closing, therefore, I would like to propose that extreme care must be taken to perform the proposed research correctly the first time. Toward that end, I propose that a panel of respected experts be brought together to oversee, on a regular basis, the program design, formulation, and study performance. As the program evolves, this panel will direct research efforts to resolve the issues in a most effective manner. The objective of the proposed research program is to protect the public health and welfare in indoor environments. I believe it can be attained within the next few years. Thank you.

Mr. FUQUA. Thank you very much, Dr. Moschandreas.

Dr. Woods.

Dr. WOODS. Thank you, Mr. Chairman. Good morning.

My name is James Woods. I am a professor of mechanical engineering and architecture at Iowa State University. I am also a member of the American Society of Heating, Refrigerating & Air Conditioning Engineers. I am a registered professional engineer in Iowa. My testimony is based on research and practice I have been involved in personally for the last 20 years in the field of heating, ventilating, and air-conditioning.

I have also been authorized by ASHRAE to speak on its behalf regarding this subject. The American Society of Heating, Refrigerating & Air Conditioning Engineers is a nonprofit organization whose objective is to advance the arts and sciences of heating, refrigeration, air-conditioning and ventilation, the allied arts and sciences, and related human factors for the benefit of the general public. Founded in 1894, it consists of some 50,000 members from around the world. The society maintains headquarters in Atlanta, Ga., and an office in Washington, D.C.

I have prepared a written statement and wish to present an oral summary at this time.

The conflict between energy conservation and indoor air quality is as old as our human desire to protect and shelter ourselves. Firewood had to be gathered, dried, and stored. Fires for heating and cooking were often built inside the mouth of the caves. These conflicts still exist today when we allow ventless combustion appliances to be used indoors for heating and cooking and when we allow smoking indoors.

Today approximately one-third of the total annual energy consumption in the United States is consumed to meet thermal and air quality requirements within residential and commercial buildings. As much as 50 to 60 percent of this energy has been attributed to ventilation systems. Thus, it is no wonder that efforts to reduce energy consumption in buildings often include measures to reduce the amount of outdoor air which is allowed to enter these buildings.

Within the last 10 years we have probably witnessed more changes in control strategies for buildings than in all previous time. During this period, if the energy shortages, economic pressures and indoor environmental requirements have taught us anything about environmental control, it is that as buildings become more energy efficient, they become less forgiving environmentally.

We can no longer afford to size or operate heating and ventilating systems that are much larger than those required by design conditions, to design or operate ventilation systems with fixed 100 percent outdoor air provisions, or to control buildings at the same thermal values during unoccupied and occupied periods. Consequently, system responses to large disruptions—for example, large, unexpected crowds or accidental spills in the building—may be slower than they are for older, less efficient systems.

Corollaries to this basic premise may also be expressed as, one, buildings which are controlled for environmental acceptability can operate energy efficiently; two, buildings which are controlled for energy efficiency may not operate within environmentally acceptable criteria; and three, energy efficiency is a necessary but not sufficient criterion for environmental acceptability.

Room air distribution. One of the primary factors that has been identified as influencing environmental control in energy efficient buildings is the amount of ventilation, either natural or mechanical, that must be provided to the occupants. However, before addressing this issue, a clear understanding of the meaning of ventilation is necessary.

The physiologist commonly defines ventilation as "the inspiration of fresh air, followed by the expiration of some alveolar gas." By this definition, the quality of the inspired air is assumed to be fresh or acceptable whether the person is indoors or outdoors.

Conversely, the engineer defines ventilation as "the process of supplying and removing air by natural or mechanical means to or from any space. Such air may, or may not, be conditioned."

The source of the ventilation air in this latter definition is that portion of supply air which is outdoor air, plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality according to ASHRAE standard 62-1981. This standard also states that if the contaminant levels in the outdoor air exceed specified values, that air is to be treated before it is used for ventilation.

Clearly, these two definitions are related but they are not synonymous. The difference is fundamental and a cause of much misunderstanding regarding the quality of the air to which occupants are exposed.

A concentrated area of research is needed to resolve the problems that have resulted from these misunderstandings. Through intense scientific discussions which have been held within the last 6 months, there is a strong feeling among researchers in this field that patterns of air movement within occupied spaces are as important as specifying and controlling the rate of supply air into these spaces.

Terms such as ventilation efficiency and relative exposure index are now being used to quantify the amount of clean supply air entering the space which actually is delivered to the occupant. Preliminary data indicate that it is not uncommon to find less than 50 percent of the clean supply air reaching the occupant before it is contaminated. This subject is now being addressed in ASHRAE's current project to revise its standard 62-1981.

Sources of indoor pollutants. Sources of indoor contaminants exist indoors and outdoors. Outdoor sources may enter the building either through airborne routes through the makeup of air intakes and through windows and infiltration, or they may enter the building as below grade sources through cracks in foundations, floorings, and around piping sleeves. The below grade sources are of special concern because contaminants, such as industrial wastes, insecticides, and pesticides can be contained in soil which is used as fill dirt for new construction.

Indoor sources of contaminants may be classified as deriving from human activity, building materials, or indoor processes. In this latter category, contaminants from devices such as copy machines, environmental control equipment, hobby and craft supplies, and maintenance and housekeeping supplies should be carefully quantified and methods of control should be studied.

A major research effort is needed to characterize these and other sources of contaminants. This need has been identified in ASHRAE's position statement on indoor air quality which was approved by the board of directors in June 1982, and I have submitted that as an appendix to the written statement.

Methods of IAQ assessment. Another area of concern is the lack of methods available to assess indoor environmental quality in existing buildings. These assessments are necessary for two classifications of buildings: One, those with no known problems of indoor pollutants; and two, those with known problems.

Buildings with no known indoor air quality problems should be assessed as part of a good energy audit procedure. In a recent study we conducted for the Iowa Energy Policy Council, this classification of buildings was addressed and a procedure was proposed. However, the cost of that procedure was estimated to be approximately the same as the energy audit. Additional research is needed to develop simple and inexpensive methods for assessing those buildings before and after energy audits are conducted.

When indoor pollutant problems are known to exist in buildings, substantially different procedures are needed. I have been recently involved in such an analysis and find that assessment requires a thorough understanding of control strategies, thermal systems, health implications, social implications, and probably many other factors.

I believe that a concerted effort is needed to develop acceptable procedures for both buildings with known problems and those without known problems. This effort will require research as well as education of professionals and of the general public. Standard procedures of assessment should be developed for both classifications of buildings.

In summary, I believe the following needs regarding energy conservation and acceptable indoor air quality must be addressed by both governmental and private organizations such as ASHRAE:

One, the characterization of new and existing building stock with respect to their energy consumption and indoor air quality;

Two, methods of assessment of new and existing building stock with and without known indoor environmental problems;

Three, education of professionals and the general public regarding safe and comfortable ways of achieving energy conservation;

Four, methods of predicting the quality of the indoor environment and the amount of energy required to provide that quality;

Five, methods of measuring contaminants that may be at concentrations below those that can now be measured;

Six, development of new methods of control; and

Seven, development of new product and system performance standards.

Based on results of my own research, evaluation of research conducted by others, and evaluation of several building system performances, I believe that through a national effort it is possible to improve indoor environmental control without—while reducing energy consumption and life cycle costs of buildings.

The implications of these simultaneous occurrences is that it is possible to improve the well-being of the general public, to improve our conservation of natural resources, and to improve our short-term as well as long-term economic conditions.

Thank you.

[The prepared statement of Dr. Woods follows:]

Testimony

presented at

U.S. House of Representatives

Committee on Science and Technology

Joint Hearing of the Energy Development and Application Subcommittee

and the

Natural Resources, Agriculture Research and Environment Subcommittee

by

James E. Woods, Ph.D., P.E.
Professor of Mechanical Engineering
and Architecture
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and

Member of American Society of
Heating, Refrigerating
and Air-Conditioning Engineers

as

Panel Member on
Energy Conservation and Indoor Air Pollution Research
at Hearing on
Indoor Air Quality Research: Current Status
and Future Needs

August 2, 1983

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Acknowledgements

This testimony has been prepared by James E. Woods, Professor of Mechancial Engineering and Architecture; Heikki Maki, Visiting Scientist; and Katherine D. Sibold, Geographer, at the Building Energy Utilization Laboratory, Iowa State University.

We express our appreciation to Marilyn Kniss for her dedication to completing this material on time.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers has authorized Dr. Woods to speak on its behalf at this hearing.

Executive Summary

Rising costs of energy during the past decade have forced many building designers, engineers, and operators to seek ways to reduce energy consumption and save money. One of the more popular means of reducing energy consumption in buildings has been through changes made in the ventilation systems. Approximately one-third of the energy consumed annually in the US is used to meet space heating and ventilating requirements. Over 50% of that figure is attributed to ventilation system use alone.

The major concern expressed here is:
- that as buildings become more energy-efficient, they become less forgiving environmentally.

Corollaries to this are:
- buildings which are controlled for environmental acceptability can operate energy efficiently,
- buildings which are controlled for energy-efficiency may not operate with environmentally acceptable criteria, and
- energy-efficiency is a necessary but not sufficient criterion for environmental acceptability.

One of the major obstacles has been obtaining common definitions with which to work. Although initial work has started, considerable effort is still necessary to clearly define the problems: what is meant by indoor air quality, what are the patterns of air movement which affect the air quality, what are the sources of indoor pollutants, what are the necessary rates of flow of ventilating air while still considering energy-efficiency, how are buildings assessed or what methods are used to determine acceptable air quality both for buildings without known problems as well as those with known air quality problems.

Major research efforts should be to focus on:
- developing simple and inexpensive methods for assessing buildings with and without known indoor polluant problems,
- charactering new and existing buildings with respect to energy consumption and indoor air quality,
- educating professionals and the general public regarding safe and effective ways to achieving energy conservation,
- developing methods to predict indoor air quality,
- developing methods to measure contaminants at very low concentrations,
- developing new methods of controls, and
- developing product and system performance standards.

A national effort directed at the above needs can improve indoor environmental control while reducing energy consumption and life-cycle costs of buildings, improving the general well-being of the public, conserving our natural resources, and stabilizing our economy.

Oral Summary of Testimony for the Science and Technology Subcommittee Hearing on August 2, 1983.

My name is James E. Woods, Jr., and I reside at 2044 Pinehurst Drive, Ames, Iowa . I am a professor of Mechanical Engineering and Architecture at Iowa State University. I am also a member of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). I am registered as a Professional Engineer in Iowa. My testimony is based on research and practice I have been involved in personally for the last 20 years in the field of heating, ventilating and air conditioning.

I have also been authorized by ASHRAE to speak on its behalf regarding this subject. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) is a non-profit organization whose objective is to advance the arts and sciences of heating, refrigeration, air conditioning and ventilation, the allied arts and sciences and related human factors for the benefit of the general public. Founded in 1894, it consists of some 50,000 members from around the world. The Society maintains headquarters in Atlanta, Georgia, and an office in Washington, DC.

The conflict between energy conservation and indoor air quality is as old as our human desire to protect and shelter ourselves. Firewood had to be gathered, dried, and stored. Fires for heating and cooking were often built inside the mouth of the caves. These conflicts still exist today when we allow ventless combustion appliances to be used indoors for heating and cooking and when we allow smoking indoors.

Today approximately one-third of the total annual energy consumption in the United States is consumed to meet thermal and air quality requirements within residential and commercial buildings. As much as 50 to 60 percent of this energy has been attributed to ventilation systems. Thus, it is no wonder that efforts to reduce energy consumption in buildings often include measures to reduce the amount of outdoor air which is allowed to enter these buildings.

Within the last 10 years we have probably witnessed more changes in control strategies for buildings than in all previous time. During this period, if the energy shortages, economic pressures, and indoor environmental requirements have taught us anything about environmental control, it is that:

- as buildings become more energy efficient, they become less forgiving, environmentally.

We can no longer afford to size or operate heating and ventilating systems that are much larger than those required by design conditions, to design or operate ventilation systems with fixed 100 percent outdoor air provisions, or to control buildings at the same thermal values during unoccupied and occupied periods. Consequently, system responses to large disruptions (for example, large unexpected crowds, accidental spills, etc.) may be slower than they are for older, less efficient systems.

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Room Air Distribution

One of the primary factors that has been identified as influencing environmental control in energy efficient buildings is the amount of ventilation, either natural or mechanical, that must be provided to the occupants. However, before addressing this issue, a clear understanding of the meaning of ventilation is necessary. The physiologist commonly defines ventilation as "the inspiration of fresh air, followed by the expiration of some alveolar gas". By this definition, the quality of the inspired air is assumed to be fresh or acceptable whether the person is indoors or outdoors. Conversely, the engineer defines ventilation as "the process of supplying and removing air by natural or mechanical means to or from any space. Such air may, or may not, be conditioned". The source of the ventilation air in this latter definition is that portion of supply air which is outdoor air, plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality according to ASHRAE Standard 62-1981. This Standard also states that, if the contaminant levels in the outdoor air exceed specified values, that air is to be treated before it is used for ventilation. Clearly, these two definitions are related but they are not synonymous. The difference is fundamental, and the cause of much misunderstanding regarding the quality of the air to which occupants are exposed.

A concentrated area of research is needed to resolve the problems that have resulted from these misunderstandings. Through intense scientific discussions which have been held within the last six months, there is a strong feeling among researchers in this field that patterns of air movement within occupied spaces are as important as specifying and controlling the rate of supply air into these spaces. Terms, such as ventilation efficiency and relative exposure index, are now being used to quantify the amount of clean supply air entering the space which actually is delivered to the occupant. Preliminary data indicate that it is not uncommon to find less than 50 percent of the clean supply air reaching the occupant before it is contaminated. This subject is now being addressed in ASHRAE's current project to revise its Standard 62-1981.

Sources of Indoor Pollutants

Sources of indoor contaminants exist indoors and outdoors. Outdoor sources may enter the building either through airborne routes through the makeup air intakes and through windows and infiltration, or they may enter the building as below-grade sources through cracks in foundations, floorings, and around piping sleeves. The below-grade sources are of special concern because contaminants, such as industrial wastes, insecticides, and pesticides can be contained in soil which is used as fill-dirt for new construction.

Indoor sources of contaminants may be classified as deriving from human activity, building materials, or indoor processes. In this latter category, contaminants from devices such as copy machines, environmental control equipment, hobby/craft supplies, and maintenance and housekeeping supplies should be carefully quantified and methods of control should be studied. A major research effort is needed to characterize these and other sources of contaminants. This need has been identified in ASHRAE's Position Statement on Indoor Air Quality which was approved by the Board of Directors in June, 1982.

Methods of IAQ Assessment

Another area of concern is the lack of methods available to assess indoor environmental quality in existing buildings. These assessments are necessary for two classifications of buildings:

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In summary, I believe the following needs regarding energy conservation and acceptable indoor air quality must be addressed by both governmental and private organizations such as ASHRAE:

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5) methods of measuring contaminants that may be at concentrations below those that can now be measured,

6) development of new methods of control, and

7) development of new product and system performance standards.

Based on results of my own research, evaluation of research conducted by others, and evaluation of several building system performances, I believe that, through a national effort, it is possible to improve indoor environmental control while reducing energy consumption and life cycle costs of buildings. The implications of these simultaneous occurrances is that it is possible to improve the well being of the general public, to improve our conservation of natural resources, and to improve our short-term as well as long-term economic conditions.

Abstract

Recent studies have shown that energy efficiency and acceptable indoor air quality are not necessarily incompatible criteria. To the contrary, some indoor air quality control systems and strategies may result in increased acceptability at reduced energy consumption rates and operating costs.

Most of the "new" control strategies and systems have been known in principle for years. However, there has been no need to develop them until now. In this testimony, those methods and results of recent studies are reviewed briefly. Recommendations are made for further basic research for development of standards methods to access indoor air quality and for development of new devices and methods to improve energy efficiency and indoor air quality in existing and in new buildings. This testimony concentrates on indoor air quality control in residential and commercial buildings. However, the principles presented apply in most cases to industrial environments.

1.0 INTRODUCTION

1.1 Historic Perspective

Relationships between ventilation, indoor air quality, and thermal indoor environment have been known for centuries (1). American Indians used holes in the roofs of their cliff-dwellings and pueblos for natural ventilation. Like the ancient Romans, the Indians did most of their cooking outside, and used fire indoors only as a source of heat. Still, the residue that can be found on the ceilings of the spaces indicates that the mass quality of the indoor air must have been compromised to obtain some level of acceptance of the indoor thermal quality.

In the seventeenth century, King Charles I of England promulgated what may have been the first ventilation code (2,3). He specified that no house could be built with a ceiling height of less than 10 feet. He also specified that the heights of windows had to be greater that their widths. These specifications were intended to improve ventilation for removal of smoke, odors and heat.

The development of recommended ventilation rates is presented in Figure 1. Ventilation rates increased from 4 cubic feet per minute (cfm) per person in 1824 to 30 cfm per person in 1895. The value of 4 cfm per person was based on Tredgold's calculations for carbon dioxide (CO_2) requirements (4). The value of 30 cfm per person was based on Billing's recommendations for control of unknown contaminants and to restrain tuberculosis (5). In 1895, the American Society of Heating and Ventilating Engineers (a predecessor of ASHRAE) adopted one of the first ventilation standards in the U.S.

A major change in ventilation standards resulted from the experimental work reported by Yaglou, et al. in the 1930's (6). These studies recognized the importance of controlling indoor air quality as well as ventilation air quality, and reported ventilation rates in cfm per person required to provide "odor-free" environments.

The Yaglou studies have served as the primary reference in ventilation codes and standards from the last 50 years. During the last 10 years, standards around the world have been revised in response to the changing economic situation. In the latest ventilation standard of the American Society of

Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE Standard 62-1981) (7, also see Appendix 1) the minimum outdoor air requirement was set at 5 cfm per person. This value was chosen to dilute the CO_2 exhaled by occupants to a concentration of 0.25% in the indoor air. This concentration is lower than 0.5% specified by OSHA for industrial environments, but is greater than 0.1% recommended by the World Health Organization (WHO), and adopted in the current Japanese standards.

1.2 Definitions

The problem faced by many working in an interdisciplinary field relates to not having a common set of working definitions. The different definitions reflect the perspective of the individual disciplines and contribute to misunderstandings. For the purposes of this testimony, the following definitions are used:

Ventilation: "The process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned." (7).

Health: "A state of complete physical, mental, and social well-being; not merely the absence of disease or infirmity." (8).

Indoor Air Quality: "An indicator of how well the air satisfies the following conditions (9, see also Appendix 2):

-Thermal conditions of the air (i.e., the dry bulb temperature, relative humidity and velocity) must be adequate to provide thermal acceptability for the occupants as defined by ASHRAE Standard 55-1981 (10). Effects of mean radiant temperature, thermal resistance of clothing, and the occupants' activity levels must be considered in this evaluation.

-The concentrations of oxygen and carbon dioxide must be within acceptable ranges to allow normal functioning of the respiratory system.

-The concentrations of gases, vapors, and aerosols should be below levels that can have deleterious effects, or that can be perceived as objectionable by the occupants.

Acceptable Air Quality: "Air in which there are no known contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction." (7).

Acceptable Thermal Environment: "An environment which at least 80% of the occupants would find thermally acceptable." (10).

Thermal Comfort: "That condition of mind which expresses satisfaction with the thermal environment." (10).

Air Quality Comfort: No definition has been established.

2.0 ENERGY CONSERVATION POTENTIALS AND INDOOR AIR QUALITY

Thermal and indoor air quality control in residential and commercial buildings requires approximately one-third of the total annual energy consumption in the United States (11). Ventilation systems have been reported to require as much as 50% or 60% of the total energy consumed in buildings. Hence, ventilation represents a significant energy savings potential.

In recent studies by Fullarton, Contothanissis, and Klaber, the energy use of 100 state buildings and 176 state office buildings in Iowa and the energy use of office buildings in New York was analyzed (12,13,14). The data were taken during the same period. The ages of the buildings varied; the newest ones being constructed in the mid-1970's and the oldest one before 1900. The studies showed that the average energy consumption of the buildings from different decades was about the same (see Figure 2). Moreover, the variation in the energy consumption within a decade was at least as great as the variation between decades. As shown in Figure 3, the percentage of energy consumed as electricity was much higher in the new buildings. Another study indicates that both the total energy consumption and indoor environment conditions are about the same in an old and a new building (15). However, this study indicates that a space in a new building may require less net energy to maintain the same environmental conditions than a space in an old building. The results described above indicate that primary energy saving potentials in newer buildings relate to the performance and operation of the HVAC (Heating, Ventilating and Air-Conditioning) systems. In the older buildings, relevant saving potentials are mainly structural (e.g., the building envelope).

The existing building stock is expected to dominate the total volume of buildings for at least the next 20 years. Therefore, research and conservation efforts should be directed toward existing buildings as well as new buildings.

Within the last ten years we have have probably witnessed more changes in control strategies for buildings than in all previous time (16). During these last ten years, if the energy shortages, economic pressures, and indoor environment requirements have taught us anything about environmental control, it is that:

-as buildings become more energy efficient, they become less forgiving environmentally

We can no longer afford to size or operate heating systems that are much larger than those required by design conditions, to design or operate ventilation systems with fixed 100% outdoor air provisions, or to control buildings at the same thermal values during unoccupied and occupied periods. Consequently, system responses to large disruptions (e.g., large unexpected crowds, accidental spills, etc.) may be slower than they are for older, less efficient systems.

Corollaries to this basic premise may also be expressed as:

-Buildings which are controlled for environmental acceptability can operate energy efficiently.

-Buildings which are controlled for energy efficiency may not operate within environmentally acceptable criteria.

-Energy efficiency is a necessary, but not sufficient, criterion for environmental acceptability.

3.0 FUNCTIONS OF HEATING, VENTILATING AND AIR-CONDITIONING SYSTEMS

HVAC systems have two major purposes:

- -to provide an acceptable thermal environment in the occupied space
- -to provide acceptable air quality in the occupied space

Both functions are often accomplished by means of one system. In this case, the system has to be designed, operated and controlled in the way that at least minimum thermal and air quality acceptabilites are maintained in all operating situations. All current systems do not fulfill these conditions (16). For example, a variable air volume (VAV) systems with terminal reheat is only thermally controlled. When less cooling power is needed, the supply air flow rate is decreased. If the internal load of a building is high due to high occupancy, this internal load reduces the heating power required during a heating period, and the VAV system operates at minimum supply air flow.

The minimum acceptable air quality requirement is not fulfilled if a ventilation system with air recirculation possibility is misused and excessive air is recirculated, thus reducing the required amount of outdoor air for ventilation.

Interactions between the function of existing systems, indoor air quality and thermal environments should be investigated to prevent the misuse of current systems. Both functions of HVAC systems should be stressed when developing and designing new systems (16). This topic is now being addressed by the ASHRAE Standards Project Committee which is revising ASHRAE Standard 62-1981.

4.0 SOURCES OF INDOOR CONTAMINANTS

4.1 Environmental Zones

To characterize the sources of indoor contaminants, it is first necessary to define the four environmental zones which influence the occupants. One such characterization has been proposed as (17):

1. The micro-environment contains those factors to which the occupant is intimately exposed and includes such boundaries as clothing and respirable air.

2. The mini-environment contains those factors that are most commonly controlled to meet the requirements of the occupants. It includes such boundaries as walls, ceilings, and floors but excludes the boundaries of the micro-environment. Several mini-environments may exist within a building.

3. The meso-environment contains those external factors that perturb control of the mini-environments. It includes such boundaries as property sites or local landscaping but excludes the boundaries of the mini-environment.

4. The macro-environment contains those factors that are external to the other zones. The macro-environment has a strong influence on control of the mini-environment.

4.2 Classification of Contaminants

Contaminants found indoors may be classified into four groups- gases and vapors; particles, either viable or non-viable; and radionuclides (18).

4.3 Characterization of Sources

Little is known about the emission of pollutant sources. In current guidelines, the emission rates are often assumed to be constant or the emission is known only in one situation (see Table 1). However, all pollutant sources are variable . For example, respiration rate depends strongly upon a person's metabolic rate. Emission from a cigarette depends upon the properties of the tobacco, paper, filter, and on the way it is smoked. Moreover, the total exposure depends on the number of smokers and their occupancy patterns.

Sources which are not directly affected by people are variable, too. Emissions from new building materials can be high but may decrease over time; outdoor sources depend on the weather, etc.

Substantial interactions exist between different pollutants and emission sources. For example, formaldehyde emission from particle board depends on the air humidity (19); radon and radon progeny levels depend on airborne particle concentration (20); nitrogen oxides react with water vapor and building materials, and so on.

Both qualitative and quantitative research efforts are needed on the dynamic behavior of pollutant sources and on the interaction between pollutants. Subsequently, models should be developed to simulate sources and interactions. These models are needed as a part of the comprehensive ventilation and indoor air quality models. These needs have also been identified in ASHRAE's Position Statement on Indoor Air Quality (21, also Appendix 3).

4.4 Outdoor Sources

The quality of outdoor air must be known when using it for dilution of indoor contaminants. ASHRAE Standard 62-1981 recognizes this fact and gives standard and guideline concentration values for several outdoor contaminants (see Tables 2 and 3). If outdoor air quality is not acceptable, it must be cleaned by appropriate techniques before its use as ventilation air.

Contaminant sources in the macro-environment can be divided into natural and anthropogenic (man-made) sources (18). Natural sources emit many pollutants several times more than anthropogenic sources. For example, cosmic and solar radiation generates nitrogen oxides 3 to 12 times more than combustion processes. However, anthropogenic sources can disturb natural balances affect the macro-environment, and thus affect the mini-environment in the buildings. Moreover, many artificial processes emit pollutants which do not exist naturally and which can be carried into the indoor environment.

Pollutant sources in the meso-environment can be classified as those which are above the ground and those which are below the ground (18). The above-ground meso-environment is important because it is the source of the supply air for the building. Sources in the meso-environment are often the result of building systems. For example, ventilation exhaust air or flue gases of a furnace can drift into the make-up air of a ventilation system due to the improper placement of the system components.

Pollutant sources in the below-ground meso-environment mainly consist of utility systems (sewers, water and gas pipes) and the soil. Recent studies have shown that landfill below the building can have extremely high concentrations of radon and industrial waste (22,23). Those pollutants can become airborne and enter the building by infiltration or ventilation, or they may diffuse into the building. Additional research is needed to determine how the macro- and meso-environments affect indoor air quality (i.e. interactions between macro-, meso-, and mini-environments).

4.5 Indoor Sources

If the presence of an indoor contaminant is due to internal sources rather than outdoor air, the magnitude of the contaminant's net generation rate ($\dot{N}$) must be quantified for indoor air quality calculations (11,24). Numerous types and sources of internally generated contaminants have been identified including at least 15 bioeffluents from human occupancy (25), over 200 odorous compounds from building materials (26), and more than 3,000 compounds from tobacco smoke (11). The physical nature of indoor contaminant generation also varies from single point sources (e.g., cooking processes) to large area sources (e.g., building outgassing). Some known contaminant generation rates from indoor sources are given in Table 1.

Indoor sources directly affect indoor air quality. Potentially, the best method for improving indoor air quality and reducing energy consumption is to minimize or remove, if possible, the emission sources (see 6.2 Source Control). Research is needed to quantify the emissions of different building materials and processes and to identify effective source control. For example, smoking and non-smoking areas within buildings should be documented in terms of contaminant levels and energy consumption. Another example is the effectiveness of contaminant removal devices which can be incorporated in unvented combustion appliances. A third example is the effectiveness of maintenance procedures in controlling the emission of viable and non-viable contaminants from building components.

5.0 HUMAN RESPONSES

As this subject will be discussed by other panel members, we have only mentioned human responses to indicate differences that should be considered in terms of continuous and intermittent exposures, in terms of disaggregate and interactive effects, and in terms of objective and subjective responses.

5.1 Stress-Strain Relationships

Occupants respond to exposure within the environment in one of several ways. The relationship between occupant and environment,as shown in Figure 4, a micro- or mini- environmental force, pressure, or influence (stress) indicates that results in a physiological or pychological response (strain) as a function of the predisposition of the occupant to the stress (susceptibility). Susceptible populations must be considered if acceptability of the indoor environment is to be achieved.

Rohles (27) in his Ecosystem Complex (see Figure 5) relates physical factors to organismic factors and adaptive factors. The number of physical factors or stressors to which an occupant may be exposed is large. In the attempt to systematically characterize some of the physical factors, they can be separated into two categories, mass stressors and energy stressors and represented as dimensional continua (see Figure 6). Mass stressors can be characterized by particle size with energy stressors characterized by wavelengths. The distinction is useful in the selection of indoor environmental control strategies.

5.2 Characterization of Human Responses

Short term objective responses to high concentrations of pollutants are relatively well known. For example, responses to airborne formaldehyde above 3.0 ppm are presented in Table 4. However, little is known about the stress effects of long term exposures to low concentrations. For instance, formaldehyde exposure in a home is usually relatively low and continuous, (i.e., less than 0.1 ppm). Moreover, subjective responses to intermittent exposure, for example, tobacco smoke, are not well documented.

Evidence exists that interactive effects may be at least as important to our reponses as the disaggregate effects. For example, a study (28) indicates that thermal sensations are related to carbon dioxide concentrations. In the study, the students felt warmer when CO_2 concentration rose. As a second example, indications have been found that the enthalpy (temperature and humidity) of air strongly influences the acceptability of an indoor space containing tobacco smoke; when temperature and humidity rise, human perception of smoke odor decreases. (17)

Legionellosis is an example of a response caused by a bacteria, Legionella pneumophila . This bacteria apparently has it's natural habitat outdoors but, since it favors warm and humid environments, it can accumulate in air humidifiers, hot water systems, cooling towers, etc., if they are not maintained properly.

A long term research plan is needed to characterize human responses to indoor environmental stressors. This is an area where the government and private sectors should work closely together. As an example, ASHRAE's Position Papers on Legionellosis (also see Appendix 4), approved by it's Board of Directors in 1981, calls for research it can sponsor, and research that will require the resources of governmental agencies. In both cases, close cooperation should be fostered.

6.0 METHODS OF INDOOR AIR QUALITY CONTROL, PREDICTION, AND ASSESSMENT

6.1 Control Strategies

Indoor air quality is one of the two main parameters which may be controlled by ventilation. Ventilation can be controlled by two different strategies:

- Indirect Control Strategy

- Direct Control Strategy

Indirect Control Strategy is the most common strategy used presently. In this strategy, designers use the ventilation rates needed (usually cfm per person or per floor area) from a standard table (e.g., Ventilation Rate Procedure in ASHRAE Standard 62-1981). Designers can also estimate the emission rates of pollutants and calculate ventilation rates or removal rates of an air cleaning device needed to achieve acceptable indoor air quality (Indoor Air Quality Procedure in ASHRAE Standard 62-1981). In both design methods, ventilation and removal rates must be chosen on the basis of "design conditions". Even then, there is no guarantee that indoor air quality will be acceptable in all operating situations if the air quality is not monitored. Indirect control strategies are usually less energy efficient if pollutant generation rates are highly variable (see 4.3, Characterization of Sources). To provide for improvements of indoor air quality and energy efficiency, inexpensive passive pollutant samplers should be developed for monitoring the operation of the indirectly controlled ventilation systems.

In Direct Control Strategy, the concentration(s) of indoor air pollutant(s) are monitored continuously and they are kept at or below acceptable levels by regulating the ventilation rate or the removal rate of an air cleaning device. With feedback from the air quality to the ventilation system, the ventilation rates can be minimized to reduce energy consumption.

As the number of indoor pollutants is numerous, it is neither practical nor even possible to monitor all of them. Research is needed to determine relationships between the concentrations of various pollutants in different indoor environments so that characteristic pollutants can be identified for control purposes. Also, reliable and inexpensive sensors should be developed so that controllers for those characteristic pollutants can be developed.

Two studies have recently been reported in which indoor air CO_2 concentration was used as the control parameter of the ventilation systems (30,31). Energy savings from 20% to 40% compared to conventional control strategies were reported. These savings were achieved while maintaining the same or better air quality than with conventional strategies.

6.2 Control Systems

A simple steady state ventilation model can be used to demonstrate the three methods of indoor air quality control that are most commonly employed : source control, removal control, and dilution control (1,18). The mass balance of a single compartment model may be expressed as:

$$\Delta C = \frac{\dot{N} - \dot{E}}{\dot{V}}$$

where

$\Delta C = C_r - C_o$ = the difference between the uniformly mixed indoor air concentration C_r, and the outdoor air concentration C_o

$\dot{N}$ = the net generation rate of the contaminant

$\dot{E}$ = the removal rate of the contaminant in the air cleaner device

$\dot{V}$ = the outdoor air flow rate (dilution air)

The source control affects $\dot{N}$, the removal control affects $\dot{E}$, and the dilution control affects $\dot{V}$.

The following conclusions can be drawn from the mass balance:

1. If removal control is not employed, the indoor air concentration will exceed the outdoor concentration unless the source is removed or an infinite dilution rate is provided.

2. If the indoor contaminant concentration is to be less indoors than outdoors and the dilution rate is finite, the removal rate, $\dot{E}$, must exceed the net generation rate, $\dot{N}$.

3. Outdoor air required for dilution control may be reduced, if alternative source control and removal control strategies are sufficient to provide the same quality of indoor air as would be achieved by dilution control.

The most important conclusion is, however:

4. To achieve an acceptable C_T economically, a combined strategy of source, removal, and dilution control may be required.

Therefore all three control systems should be researched and developed:

- For source control, research is needed on methods to reduce the strengths of pollutant sources.

- In removal control, new, more efficient and cost-effective air cleaning devices should be developed. Also, the development of standards methods of evaluation these devices is needed.

- In dilution control, research is needed on methods to increase ventilation efficiency (see 6.3 Ventilation Models).

6.3 Ventilation Models

A gap exists between the physiological and engineering definitions of ventilation. The common physiological definition is: "The inspiration of fresh air and the expiration of some alveolar gas" (32) . The engineering definition is: "The process of supplying and removing air by natural or mechanical means to and from a space" (7). Supplying and removing air to and from a room does not guarantee that the inhaled air is clean, even though the supply air would be clean and the supply air flow rate would be "sufficient". Supply air can flow directly from the supply air diffuser to the return air grille without passing through the occupied zone (short circuit), or the supply air can pass through a polluted zone before entering the occupied zone. These problems are usually due to inappropriate placement or inadequate functioning of supply and return air devices (in other words, due to poor design, construction or operation). Physical phenomena, such as thermal stratification of room air, can disrupt the supply air distribution to the occupied zone. Moreover, the function of a system can be very sensitive to the changes of the operating conditions, e.g., summer versus winter conditions, a room fully occupied versus partly occupied, or a forced air furnace which cycles on and off (9,33).

The supply air distribution may be evaluated by a parameter called Ventilation Efficiency (9,33,34,35). It is a qualitative measure of the functioning of a ventilation system, and it describes how well the supply air is distributed into different parts of a room. Ventilation Effieciency can be calculated from the equation (9):

$$\varepsilon_i = \frac{\int_0^\infty C_r \, dt}{\int_0^\infty C_i \, dt}$$

where:

ε_i = Ventilation Efficiency in the point i

C_r = Concentration of the tracer gas in the reference point

C_i = Concentration of the tracer gas in the point i

and all initial concentrations are equal.

Although the principals of ventilation efficiency have been known for decades, no systematic research has been done on the subject until recently.

Ventilation Efficiences can differ significantly within a house (9) as well as within a room. Therefore, the exposure to pollutants a person experiences depends upon the person's locations within the room. The Relative Exposure Index is a measure of this exposure. It tells how high the exposure is at a certain point of a house or a room compared to a reference point. It can be calculated by the equation (32):

$$E_i = \frac{\int_0^\infty C_i dt}{\int_0^\infty C_r dt}$$

where:

E_i = Relative Exposure Index in the point i

C_i = Tracer gas concentration in the point i

C_r = Tracer gas concentration in the reference point

and the tracer gas is released at the contaminant source

Thus, the Relative Exposure Index depends upon the room air movements and upon the location of the pollutant sources, while Ventilation Efficiency is a criterion of ventilation distribution which does not depend on the pollutant source.

Theoretical models which similate three-dimensional room air flows are possible in principle. However, they require large computational facilities, and, hence, they are not pratical, yet. Rather, multizone ventilation models have been developed (11). These models describe interactions between uniform zones (rooms, or zones within rooms) and they can be used to predict the dynamic behavior of pollutant concentrations. If room air flows are steady, the model parameters can be solved by using tracer gas tests. However, these models can be used as theoretical tools, in which the model parameters are assumed, to demonstrate the effect of different parameters.

More research is needed on ventilation models since air movement in a space is at least as important as ventilation air flow rate. Improved supply air distribution enhances energy economics and thermal acceptability since acceptable indoor air quality can be achieved by lower ventilation air flow rates. Lower ventilation rates lead to smaller ventilation systems which take less space and initial costs.

6.4 Characterization of Removal

Removal of air pollutants by other means than dilution can be divided into two categories (24).

Passive Removal. Within indoor spaces, the concentrations of particulate contaminants may be significantly reduced by settling of the particles. Other passive particulate removal mechanisms are ion diffusion charging, thermophoresis, photophoresis and coalescence (36).

Some evidence is found which indicate that gases, such as sulfur dioxide, nitrogen oxides, and carbon monoxide, may be absorbed on building materials (11). Moreover, some gases react with materials, with other pollutants, and due to radiation. These reactions can deteriorate building materials and generate new pollutants. Since little is known about passive removal of gases in occupied spaces, this is an area in need of significant research.

Active Removal is achieved by air cleaner devices. Conventional devices include mechanical filters, electronic air cleaners, and an air washer for aerosols, and a sorption media for gases and vapors. Removal mechanisms in these devices are complicated (24). Low and medium efficiency mechanical filters are common in HVAC units and the use of electronic air cleaners is expanding. Hence their functions are relatively well known. However, additional work is needed to develop standard techniques to evaluate the air cleaner performance as a unit and within a system. This subject is being addressed by the ASHRAE Standards Project Committee which is revising Standard 52-76(36). A concentrated effort is needed in the development of gas (sorption) filters and their applications for indoor air quality control. A research project is being sponsored by ASHRAE on this subject (37). However, extensive additional work is needed. For example, technology transfer from gas-mask theory and practice might be appropriate.

6.5 Methods of Assessment

Presently energy audits are conducted in buildings to identify possible means to improve energy efficiency. These audits often suggest measures which have an effect on indoor air quality; e.g., air flow rates can be readjusted and the building envelope can be renovated. Both of these measures can reduce dilution. Therefore indoor air quality evaluation should be included in the total assessment procedure to ensure that the building is not only energy efficient and economical, but is also environmentally acceptable (see Figures 7 and 8).

The above mentioned method is useful when no indoor air quality problems have been reported. In a building, in which problems are suspected, the assessment procedure must be substantially different. A suggested flowchart is shown in Figure 9. After characterizing the problem and interviewing occupants, source areas must be located. Then, indoor air quality control systems and control strategies must be analyzed and compared to design values.

After rationalizing actual system with the design system, thermal loads of the building (or of the zone which is surveyed) must be analyzed to identify possible interactions between thermal and air quality control (e.g., internal loads can be so high that a thermostatic heating/ventilation unit does not operate). Measurements may be needed to complete the final analysis.

The assessment methods presented here are only suggested solutions and a major research effort is needed in this regard. Special attention should be given to the methods of measurement. Currently available instrumentation is expensive and time consuming to operate, or inexpensive and of questionable accuracy and precision. Hence the indoor air quality assessment is currently an expensive procedure.

After appropriate instrumentation and procedures become available, standard methods of assessment should be developed.

7.0 NATIONAL NEEDS IN ENERGY CONSUMPTION AND INDOOR AIR QUALITY

In summary, the following needs regarding energy conservation and acceptable indoor air quality should be addressed by both governmental and private organizations.

1) the characterization of new and existing building stock with respect to their energy consumption and indoor air quality,

2) methods of assessment of new and existing building stock with respect to indoor environmental problems,

3) education of professionals and the general public regarding safe and comfortable ways of achieving energy conservation,

4) methods of predicting the quality of the indoor environment and the amount of energy required to provide that quality,

5) methods of measuring contaminants that may be at concentrations below those that can now be measured,

6) development of new methods of control, and

7) development of new product and system performance standards.

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Table 1. Examples of net generation rates, $\dot{N}$, from sources of indoor contaminants (16)

	Generated Contaminants				
		Particles			
Source of Contaminant	Gases & Vapors	Non-viable	Viable	Radionuclides	Comments*
1.0 Human Activity					
1.1 Respiration	O_2: -38g/hr person				O_2 uptake derived from Ref. 1, p. 41 assuming adult sedentary activity. Values may increase 10x
	CO_2: 32g/hr person				Based on assumed RQ = 0.83
	H_2O: 12g/hr person				Adult sedentary activity derived from Gagge, et al, Ref. 6
1.2 Skin transport	H_2O: 17g/hr person				Adult sedentary activity, derived from Gagge et al., Ref. 6. Value may increase 10x due to sweating
		~ $7x10^6$ scales/min person	~ $28x10^6$ bacteria/min person		From Clark & Cox, Ref. 37
2.0 Building Materials					
2.1 Masonry products				Radon: 0.2-2.0 pCi/kg hr	From Colle, Ref. 39 p. 53
2.2 Wood products	HCHO: 0.035-0.41mg/hr m^2 surface area				From Wadden and Scheff, Ref. 40
2.3 Insulation	HCHO: 3-10µg/hr/g foam				From Wadden and Scheff, Ref. 40
3.0 Combustion					
3.1 Tobacco Smoking	CO: 51.6mg/cig CO_2: 443mg/cig	Nicotine: 4.2 mg/cig			From Woods, Ref. 41
	aldehydes 114 ug/cig NH_3: 5.2 mg/cig	Phenols: 636 µg/cig			
	hydrogen cyanide: 65 µg/cig	Pyradines: 1.3 mg/cig			
	NO_x: 79 µg/cig acrolein: 11µg/cig	Total suspended 31.9 mg/cig			
3.2 Ventless kerosene heaters	O_2:-(3-4) g/g fuel CO:0.5-3.0 g/g CO_2: 3.0 g/g NO: 0-0.7 mg/g NO_2: 0.2-0.7mg/g SO_2: 0.6-0.8mg/g				From Leaderer, Ref. 42
	H_2O: ~1.3 g/g				From Olivieri, Ref. 43

*References in Woods (16)

Table 2.(Table 1 in ASHRAE Standard 62-1981). National ambient air quality standards.* (19)

Contaminant	Long Term		Short Term	
	Level	Time	Level	Time
Carbon Monoxide			40 mg/m^3	1 hr
			10 mg/m^3	8 hrs
Lead	1.5 μg/m^3	3 mo		
Nitrogen Dioxide	100 μg/m^3	yr		
Oxidants (Ozone)			235 μg/m^3	1 hr
Particulates	75 μg/m^3	yr	260 μg/m^3	24 hrs
Sulfur Dioxide	80 μg/m^3	yr	365 μg/m^3	24 hrs

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*See Reference 11 in Standard 62-1981. Pertinent local regulations should also be checked. Some regulations may be more restrictive than those given here, and additional substances may be regulated.

Table 3. (Table 2 in ASHRAE Standard 62-1981). Additional ambient air quality guidelines. (13)

Contaminant	Long Term		Short Term		Reference in Standard 62-1981
	Level*	Time	Level	Time	
Acetone-0**	7/mg/m^3	24 hrs	24 mg/m^3	30 min	12
Acrolein-0			25 μg/m^3	C***	13
Ammonia-0	0.5 mg/m^3	yr	7 mg/m^3	C	14, 15
Beryllium	0.01 μg/m^3	30 days			13
Cadmium	2.0 μg/m^3	24 hrs			16
Calcium Oxide (Lime)			20-30 μg/m^3	C	17
Carbon Disulfide-0	0.15 mg/m^3	24 hrs	0.45 mg/m^3	30 min	12
Chlorine-0	0.1 mg/m^3	24 hrs	0.3 mg/m^3	30 min	12
Chromium	1.5 μg/m^3	24 hrs			12
Cresol-0	0.1 mg/m^3	24 hrs			13
Dichloroethane-0	2.0 mg/m^3	24 hrs	6.0 mg/m^3	30 min	12
Ethyl Acetate-0	14 mg/m^3	24 hrs	42 mg/m^3	30 min	12
Formaldehyde-0			120 μg/m^3	C	13
Hydrochloric Acid-0	0.4 mg/m^3	24 hrs	3 mg/m^3	30 min	12, 15
Hydrogen Sulfide-0	40-50 μg/m^3	24 hrs	42 μg/m^3	1 hr	17 (7 states)
Mercaptans-0			20 μg/m^3	1 hr	16
Mercury	2 μg/m^3	24 hrs			16
Methyl Alcohol-0	1.5 mg/m^3	24 hrs	4.5 mg/m^3	30 min	12
Methylene	20 mg/m^3	yr	150 mg/m^3	30 min	14
Chloride-0	50 mg/m^3	24 hrs			14
Nickel	2 μg/m^3	24 hrs			16
Nitrogen Monoxide	0.5 mg/m^3	24 hrs	1 mg/m^3	30 min	14
Phenol-0	0.1 mg/m^3	24 hrs			12, 13
Sulfates	4 μg/m^3	yr			17
	12 μg/m^3	24 hrs			(4 states)
Sulfuric Acid-0	50 μg/m^3	yr	200 μg/m^3	30 min	14
	100 μg/m^3	24 hrs			14
Trichlorethylene-0	2 mg/m^3	yr	16 mg/m^3	30 min	14
	5 mg/m^3	24 hrs			
Vanadium	2 μg/m^3	24 hrs			16
Zinc	50 μg/m^3	yr			14
	100 μg/m^3	24 hrs			14

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*Unless otherwise specified, all air quality measurements should be corrected to standard conditions of 25° C (77° F) temperature and 760 mm (29.92 inches) of mercury pressure (101.3 kPa).

**These materials marked "0" have odors at concentrations sometimes found in outdoor air. The tabulated concentration levels do not necessarily result in odorless conditions.

***Ceiling, or maximum allowable concentrations.

Table 4. Human Responses to Airborne Formaldehyde (HCHO), MW = 30. [Adapted from Ref. 11, p.324, and Ref. 20 pp. 263-265]. (16)

Concentration		Exposure Time	Response
ppm	$\mu g/m^3$		
0 - 0.05	0 - 60	continuous	No alteration of cerebral electrical activity in subjects most sensitive to odor
0.05 - 0.50	60 - 600	5 min	Eye irritation range in unacclimated group. Increased blink rate, rate proportional to HCHO concentration
0.05 - 1.0	60 - 1200	1 min	Odor perception threshold
0.06 - 1.3	72 - 1560	1 min	Optical chronaxy changes in unacclimated group
0.10	120	continuous	Current indoor acceptable limit by ASHRAE Standard 62-1981
0.13 - 0.45	156 - 540	?	Complaints of temporary eye and upper respiratory tract irritation
0.3 - 217	360 - 260,000	8 hr	Annoying odor, constant prickling irritation of the mucous membranes, disturbed sleep, thirst, heavy tearing
0.5 - 7.3	60 - 8,760	daily	Increased occurrence of upper respiratory irritation
0.8	960	1 min	Altered functional state of cerebral cortex
0.8	960	daily	Equilibrium and olefactory sensation shifts; irritation of upper respiratory tract and eyes in most individuals; enhancement of alpha rhythms
0.9 - 1.6	1,080 - 1,920	8 hr	Itching eyes, dry and sore throat, disturbed sleep, and unusual thirst upon awaking in the morning
1.0	1,200	8 hr	Recommended standard by NIOSH
1 - 11	1,200 - 13,200	8 hr	Eyes, nose and throat irritation
3.0	3,600	8 hr	Current OSHA Standard
4.0	4,800	?	Complaints of irritation of conjunctiva, naso-pharynx, and skin; increased incidence of caterrhal conjunctivitis, slight reddening and drying of the skin
4.2 - 10.9	5,040 - 13,080	1 min	Unbearable without respiratory protection
13.8	13,560	30 min	Nose and eye irritation subsiding after 10 min in chamber
5 - 30	6,100 - 37,000	?	Lower airway and pulmonary effects
50 - 100	61,000 - 120,000	?	Pulmonary edema, inflamation, pneumonia
100+	120,000+	?	Death

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Figure 9. Schematic diagram of the procedure to assess indoor air quality for buildings in which prior knowledge of problems exists.

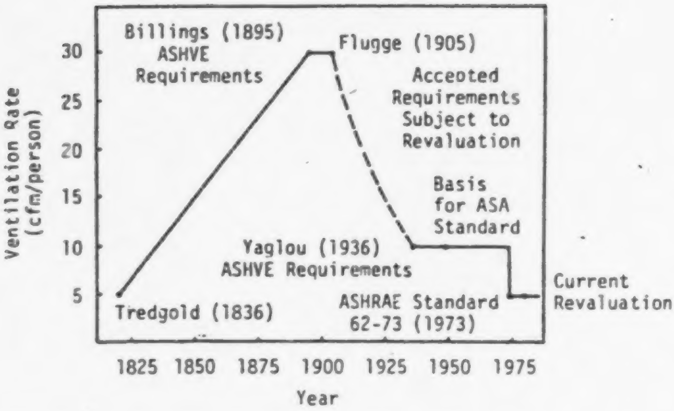


Figure 1. Historic development of required ventilation rates.(1)

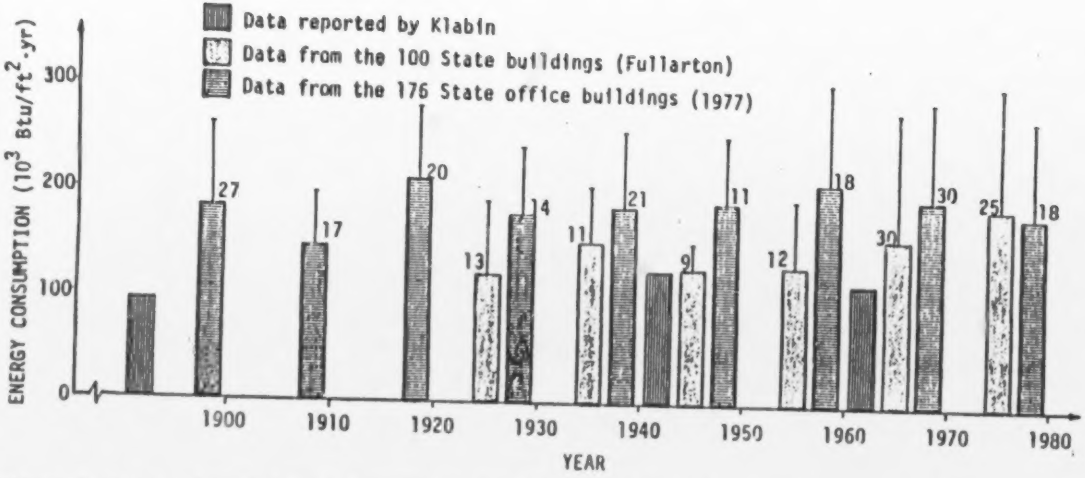


Figure 2. Average Annual Energy Consumption for Office Buildings in New York, the 100 State Buildings and the 176 State Office Buildings Surveyed in Iowa (Mean, SD). (14)

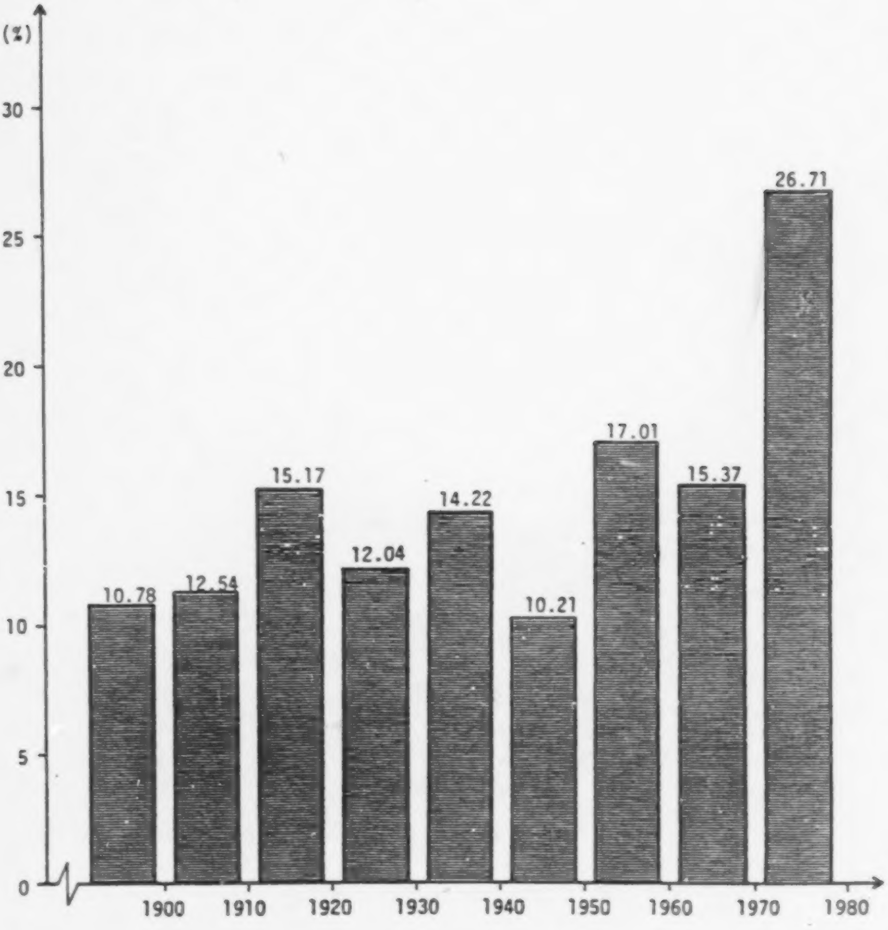
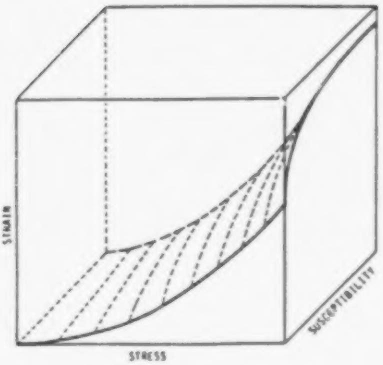


Figure 3. Electrical Consumption (% of Total Energy Consumption) for 176 State Office Buildings, as a Function of the Date Of Construction.

(14)


STRAIN
STRESS
SUSCEPTIBILITY

STRESS: An environmental force, pressure, or influence on a person

STRAIN: A physiological or psychological response to stress

SUSCEPTIBILITY: Predisposition to stress

Fig. 4. Relationships among the factors of stress, strain and susceptibility of building occupants. (17)

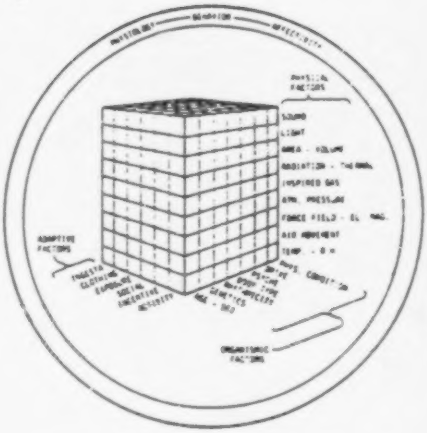

PHYSIOLOGY
BEHAVIOR
EFFECTIVITY
PHYSICAL FACTORS
SOUND
LIGHT
AREA - VOLUME
RADIATION - THERMAL
INSPIRED GAS
ATM. PRESSURE
FORCE FIELD - EL. MAG.
AIR MOVEMENT
TEMP. - R H
PHYS. CONDITION
DRIVE
PSYCHE
BODY TYPE
GENETICS
AGE - SEX
ADAPTIVE FACTORS
INGESTA
CLOTHING
EXPOSURE
SOCIAL
INCENTIVE
ACTIVITY
ORGANISMIC FACTORS

Fig. 5. Schematic representation of the Ecosystem Complex (after Rohles, 1971). (17)

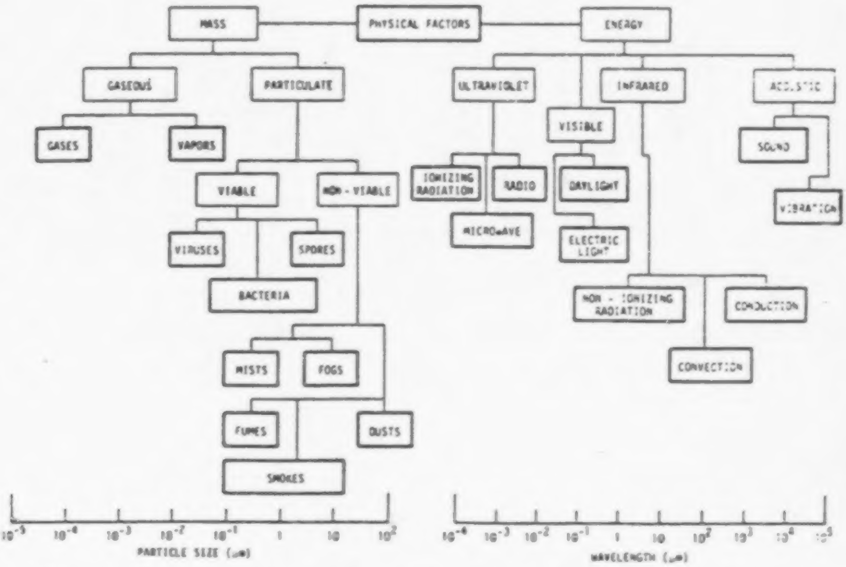

MASS
PHYSICAL FACTORS
ENERGY
GASEOUS
PARTICULATE
GASES
VAPORS
VIABLE
NON - VIABLE
VIRUSES
SPORES
BACTERIA
MISTS
FOGS
FUMES
DUSTS
SMOKES
ULTRAVIOLET
VISIBLE
INFRARED
ACOUSTIC
IONIZING RADIATION
RADIO
MICROWAVE
DAYLIGHT
ELECTRIC LIGHT
NON - IONIZING RADIATION
CONDUCTION
CONVECTION
SOUND
VIBRATION
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
PARTICLE SIZE (µm)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
WAVELENGTH (µm)

Fig. 6. Representation of mass stressors and energy stressors as dimensional continua. (17)

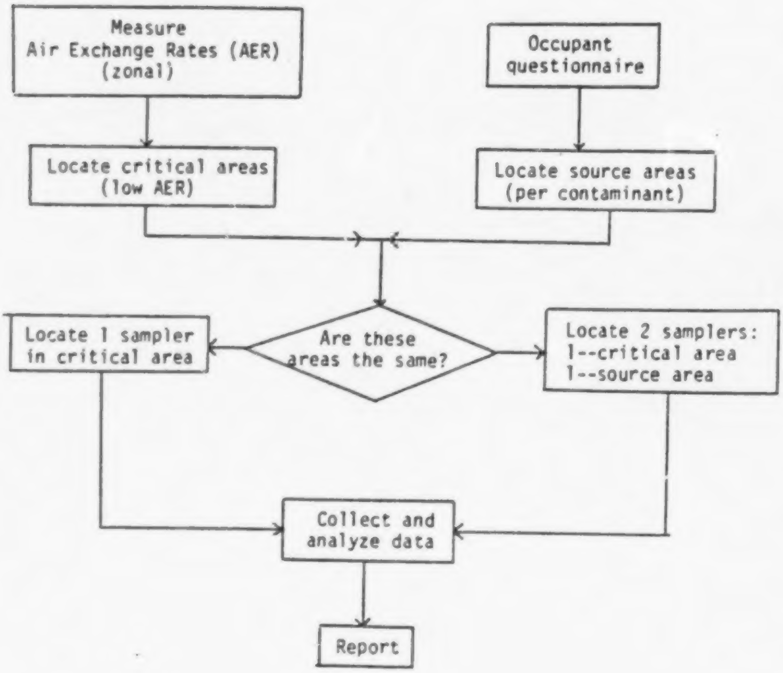

Measure
Air Exchange Rates (AER)
(zonal)
Occupant questionnaire
Locate critical areas (low AER)
Locate source areas (per contaminant)
Locate 1 sampler in critical area
Are these areas the same?
Locate 2 samplers:
1--critical area
1--source area
Collect and analyze data
Report

Fig. 7. Schematic diagram of the procedure to assess indoor air quality for residences in which no prior knowledge of problems exists. (9)

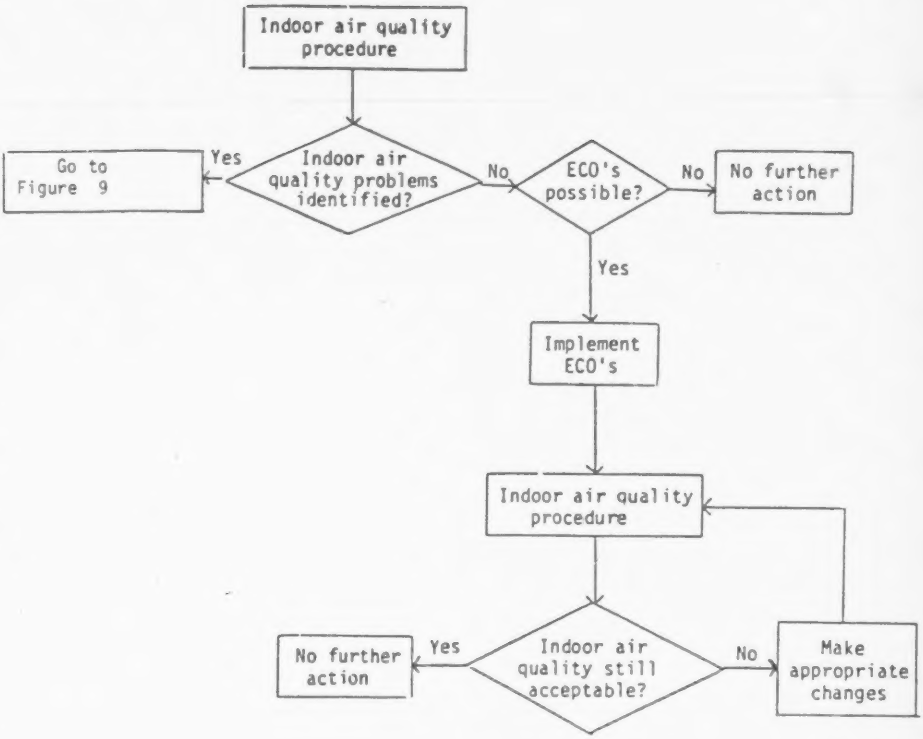

Indoor air quality procedure
Indoor air quality problems identified?
Yes
Go to Figure 9
No
ECO's possible?
No
No further action
Yes
Implement ECO's
Indoor air quality procedure
Indoor air quality still acceptable?
Yes
No further action
No
Make appropriate changes

Figure 8. Schematic diagram of the interaction between the indoor air quality procedure and energy conservation opportunities in a building with no prior knowledge of problems. (9)

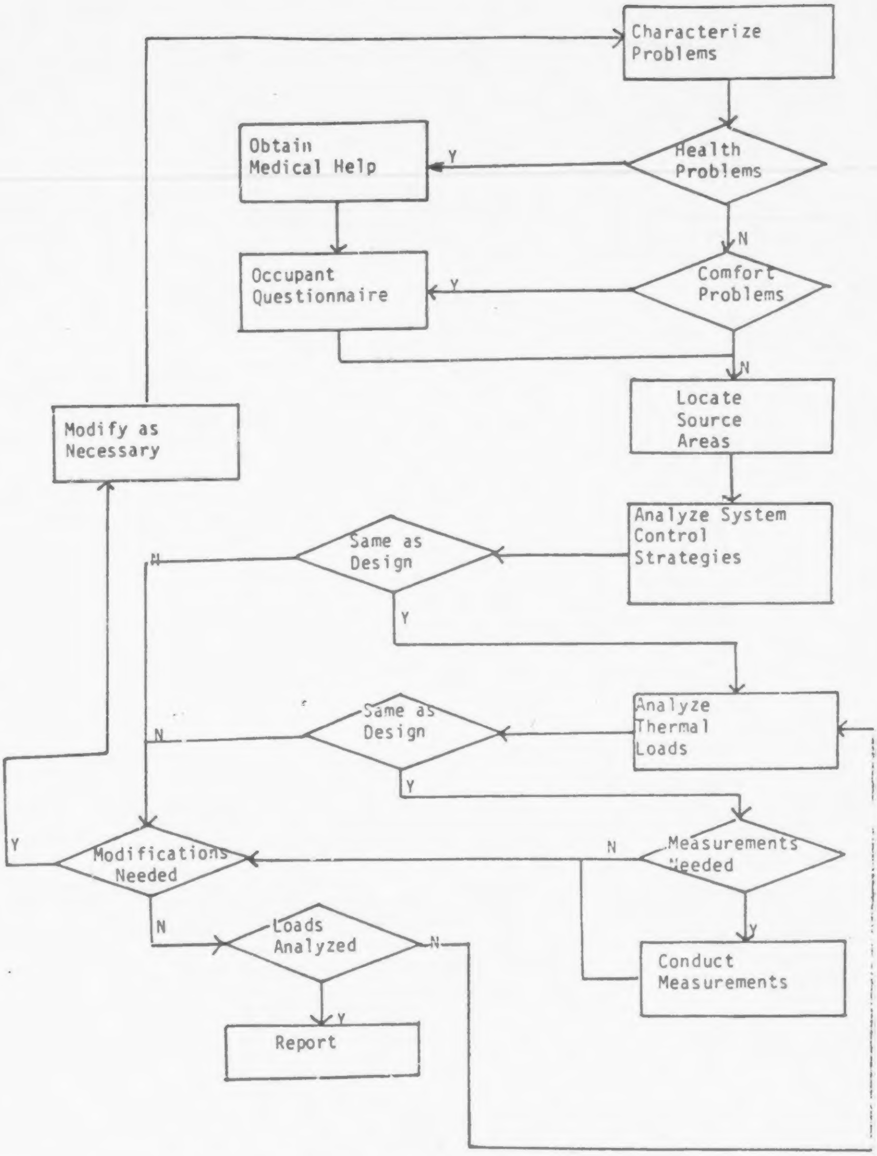

Characterize Problems
Health Problems
Y
Obtain Medical Help
N
Comfort Problems
Y
Occupant Questionnaire
N
Locate Source Areas
Modify as Necessary
Analyze System Control Strategies
Same as Design
N
Y
Analyze Thermal Loads
Same as Design
N
Y
Measurements Needed
N
Y
Modifications Needed
Y
N
Conduct Measurements
Loads Analyzed
N
Y
Report

Figure 9. Schematic diagram of the procedure to assess indoor air quality for buildings in which prior knowledge of problems exists.

JAMES E. WOODS

James E. Woods attended the University of New Mexico, where he received the Bachelor of Science degree in Mechanical Engineering in 1962. He continued his studies at Kansas State University and was awarded the Master of Science degree in Physiological Sciences in 1971 and his Doctor of Philosophy degree in Mechanical Engineering in 1974.

His experience in industry, primarily in research, includes association with the Iowa Energy Policy Council, Principal Investigator; Iowa State Research Foundation, Co-principal Investigator; Mary Greeley Memorial Hospital Bio-environmental Internship Program, Coordinator; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Principal Investigator; National Research Council, Member of Committee on Indoor Pollutants; and Iowa Class A Energy Audit Advisory Committee, Chairman.

Dr. Woods is presently a Professor in the Department of Mechanical Engineering, the Department of Architecture, and in the Engineering Research Institute at Iowa State University. He has recently been named Director of the Center for Advancement of Building Technologies and the Building Energy Utilization Laboratory at ISU.

His professional affiliations include the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), American Association for the Advancement of Science, American Society of Mechanical Engineers, National Institute of Building Sciences, National Research Council (Washington,D.C.). Dr. Woods is a registered Professional Engineer in Iowa.

He has authored or co-authored more than 75 technical papers and 3 books in the field of indoor air quality. He is also the co-holder of two patents, one on a contamination control device, and one on a solar collector. He has taught both undergraduate and graduate level courses in the field of heating, refrigeration, and air conditioning, and has been invited to speak at both national and international meetings. In ASHRAE, he has been a member of six technical committees and four standing general committees. He has also chaired the Standards Project Committee on ASHRAE Standard 62-1981: Ventilation for Acceptable Indoor Air Quality. He has served as a member of the National Reseach Council's Committe on Indoor Pollutants, and has consulted with both state and federal agencies on the subjects of energy conservation and indoor air quality.

Titles of a few of his recent publications include: "Environmental Implications of Conservation and Solar Space Heating", 1980; "Energy Efficient Indoor Air Quality Control in Hospitals," 1980; "An Experimental Validation of a Rational Model for Dynamic Responses of Buildings," 1980; "Building Energy Management Programs in Iowa," 1980; "Safe and Energy Efficient Control Stategies for Indoor Air Quality," 1981; "Energy, Environmental and Economic Interactions of Rehabilitation of Existing Buildings in Urban Renewal in Iowa," 1981; "Building Energy Management Index: An Evaluator for Performance of Existing and New Buildings," 1981; "Ventilation for Control of Indoor Air Quality," 1981; "Subjective and Objective Evaluation of a CO_2-Controlled Variable Ventilation System," 1982; "Do Buildings Make You Sick," 1982; "Sources of Indoor Contaminants," 1983; and "Calculation Methods to Assess Indoor Air Quality," 1983.

Appendix 1

ASHRAE 62-1981

ASHRAE STANDARD

Ventilation for Acceptable Indoor Air Quality

© 1981

[illegible]

1791 Tullie Circle, N.E, Atlanta, GA 30329

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ASHRAE obtains consensus through participation of its national and international members, associated societies and public review.

ASHRAE Standards are prepared by a Project Committee appointed specifically for the purpose of writing the Standard. The Project Committee Chairman and Vice-Chairman must be members of ASHRAE; while other members may or may not be members, all must be technically qualified in the subject area of the Standard. Every effort is made to balance the concerned interests on all Project Committees.

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NOTICE-AUG. 81

An industry organization has appealed the air quality limits for formaldehyde of 120 micrograms per cubic metre as shown in Tables 2 and 4 of ASHRAE Standard 62-1981. The appeal is under consideration by ASHRAE. If any change in Standard 62-1981 results from this appeal, all original recipients of Standard 62-1981 will be informed.

FOREWORD

When Standard 62-73[1] was published, a comprehensive method of establishing ventilation rates was made available. That standard emphasized ventilation air quantitites in terms of volumetric air flow rates per person and introduced the concept of "acceptable outdoor air" for ventilation purposes. It also specified the conditions under which the outdoor air quality could be increased through application of air cleaning technology.

Ventilation rates in Standard 62-73 were specified as *minimum* and *recommended* values. The recommended values generally exceeded the minimum values by factors of 1.5 to 2. ASHRAE Standard 90-75[2] used *mi*[illegible] for energy conservation purposes. ASHRAE Standard 90A-1980[3] reaffirmed this approach [illegible] and new developments in air quality control dictated that Standard 62-73 be revised.

The revised Standard includes a ventilation rate procedure which indirectly controls indoor air quality and a new procedure to permit direct control of the indoor air quality. The latter method may see increasing use in the future, since it gives the engineer or designer more freedom to achieve the objective of this Standard and to encourage innovative solutions.

The objective of this revised Standard is to provide healthful, and comfortable indoor environments by using materials and methods that optimize efficiency of energy utilization. Therefore, an interdisciplinary committee of engineers, physicians, chemists and psychologists was appointed to revise Standard 62-73.

1. PURPOSE

To specify indoor air quality and minimum ventilation rates which will be acceptable to human occupants and will not impair health.

2. SCOPE

This standard applies to all indoor or enclosed spaces which people may occupy. It does not apply to spaces where other applicable standards and requirements dictate larger amounts of ventilation air than this standard. Release of heat and moisture in residential kitchens and bathrooms, locker rooms, swimming pools, and saunas is included in the scope of this standard.

3. DEFINITIONS (SEE FIGURE 1)

3.1 ACCEPTABLE AIR QUALITY. Air in which there are no known contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction.

3.2 AIR CLEANER: a device used to remove airborne impurities such as dusts, gases, vapors, fumes, and smoke.

3.3 AIR CONDITIONING: the process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.

3.4 AIR, AMBIENT: the air surrounding an object.

3.5 AIR, EXHAUST: air removed from a space and not reused therein.

3.6 AIR, MAKEUP: outdoor air supplied to replace exhaust air and exfiltration.

3.7 AIR, OUTDOOR: air taken from the external atmosphere and, therefore, not previously circulated through the system.

3.8 AIR, RECIRCULATED: air removed from the conditioned space and intended for reuse as supply air.

3.9 AIR, RETURN: air removed from a space to be then recirculated or exhausted.

3.10 AIR, SUPPLY: that air delivered to the conditioned space and used for ventilation, heating, cooling, humidification or dehumidification.

3.11 AIR, VENTILATION: that portion of supply air which is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

3.12 CONCENTRATION: The quantity of one constituent dispersed in a defined amount of another. (See Appendix A)

3.13 CONTAMINANT: an unwanted airborne constituent that may reduce acceptability of the air.

3.14 DUST: an air suspension (aerosol) of particles of any solid material, usually with particle size less than 100 micrometers (μm).

3.15 EXFILTRATION: air leakage outward through cracks and interstices and through ceilings, floors and walls of a space or building.

3.16 FUMES: airborne solid particles usually less than 1 micrometer (μm) in size formed by condensation of vapors, sublimation, distillation, calcination, or chemical reaction.

3.17 INFILTRATION: air leakage inward through cracks and interstices, and through ceilings, floors and walls of a space or building.

3.18 GAS: a state of matter in which substances exist in the form of nonaggregated molecules, and which, within acceptable limits of accuracy, satisfies the ideal gas laws; usually a highly superheated vapor.

3.19 NATURAL VENTILATION: the movement of air into and out of a space through intentionally provided openings, such as windows and doors, or through nonpowered ventilators or by infiltration.

3.20 OCCUPIED ZONE: the region within an occupied space between planes 3 and 72 inches (75 and 1800 mm) above the floor and more than 2 feet (600 mm) from the walls or fixed air conditioning equipment (see Standard 55-1981)[4].

3.21 PARTICULATE: a state of matter in which solid or liquid substances exist in the form of aggregated molecules or particles. Airborne particulate matter is typically in the size range of 0.01 to 100 micrometers.

3.22 TOTAL SUSPENDED PARTICULATE: the weight of particulates suspended in a unit of volume of air when collected by a high volume air sampler.

3.23 VAPOR: a substance in gas form, particularly one near equilibrium with its condensed phase and which does not follow the ideal gas laws; in general, any gas below its critical temperature.

3.24 VENTILATION: the process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned.

4. CLASSIFICATION

This standard specifies alternate procedures to obtain acceptable air quality indoors:

1. By providing ventilation air of proper quality and quantity to the space (see Section 6.1), or
2. By achieving acceptable air quality within the space with respect to identified contaminants (see Section 6.2).

5. SYSTEMS AND EQUIPMENT

5.1 Ventilating systems may be mechanical or natural. When mechanical ventilation is used, provision for air flow measurement should be included. When natural ventilation and infiltration are used, the ventilation rate shall be demonstrable. When infiltration rates are insufficient to meet ventilation air requirements, mechanical ventilation shall be provided.

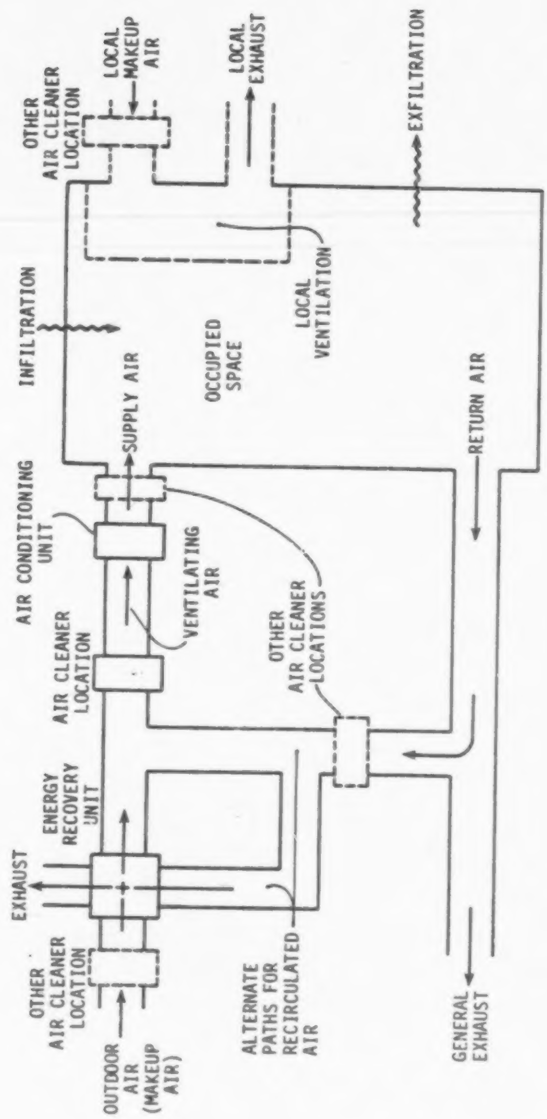
OUTDOOR AIR (MAKEUP AIR)
OTHER AIR CLEANER LOCATION
EXHAUST
ENERGY RECOVERY UNIT
AIR CLEANER LOCATION
AIR CONDITIONING UNIT
VENTILATING AIR
SUPPLY AIR
INFILTRATION
OCCUPIED SPACE
LOCAL VENTILATION
OTHER AIR CLEANER LOCATION
LOCAL MAKEUP AIR
LOCAL EXHAUST
EXFILTRATION
RETURN AIR
OTHER AIR CLEANER LOCATIONS
ALTERNATE PATHS FOR RECIRCULATED AIR
GENERAL EXHAUST

Figure 1. Ventilation System

5.2 Ventilating systems shall be designed and installed so that the ventilation air is uniformly mixed throughout the occupied zone.

5.3 Ventilating systems shall be designed and installed so that they do not cause conditions which conflict with Standard 55-1981)[4].

5.4 When the supply of air is reduced during times a space is occupied, (e.g., variable air volume systems) provision shall be made to maintain acceptable indoor air quality.

5.5 Makeup air inlets shall be located to avoid contamination of the makeup air.

5.6 Exhaust air outlets shall be located so that exhaust air does not create a nuisance or contaminate makeup air.

5.7 Ventilating ducts and plenums should be constructed entirely of incombustible, nonporous materials (UL Standard 181)[5]. Their construction shall comply with NFPA Standards 90 A and 90 B[6], and the SMACNA duct construction standards[7].

5.8 Contaminants from sources within the space should be collected as close as practicable to the source and removed.

5.9 Combustion appliances located in the conditioned space shall be provided with sufficient air for combustion and proper venting of flue gases. When infiltration supplies all or part of the combustion air, the supply rate of combustion air must be demonstrable (see Appendix B). Proper operation of clothes dryers and exhaust fans will require introduction of makeup air in tight structures.

5.10 When it is necessary to remove particulate contaminants, air filters or dust collectors should be used. Dust collectors, not air filters, should be used where the dust loading equals or exceeds 10 mg/m^3 (4 grains/1000 ft^3). Air filters and dust collectors shall be selected for the particle size and loading encountered. Filters shall be tested in accordance with ASHRAE Standard 52-76[8] or MIL STD 282[9]. Dust collectors may be wet, dry or electrostatic as required by particle size and loading (see Table 1, Chapter 11, ***ASHRAE Handbook, Equipment Volume***, 1979)[10].

Where it is necessary to control gaseous contaminants, methods based on sorption with or without oxidation should be used. Such methods are usually specific to the type of contaminant. A commonly used sorbent is activated charcoal.

Many odorous contaminants are readily oxidizable to less odorous substances, and can be controlled by passing the air through layers of pelletized oxidants such as alumina impregnated with potassium permanganate.

In the absence of an accepted standard of performance for control of gaseous contaminants, the effectiveness of control shall be demonstrated.

6. PROCEDURE

Indoor air should not contain contaminants that exceed concentrations known to impair health or cause discomfort to occupants. Such contaminants include various gases, vapors, micro-organisms, smoke, and other particulate matter. These may be present in makeup air or be introduced from indoor activities, furnishings, building materials, surface coatings, and air handling and air treatment components. Deleterious factors include toxicity, radioactivity, potential to induce infection or allergies, irritants, extreme thermal conditions and objectionable odors.

The ***Ventilation Rate Procedure*** (section 6.1) provides one way to achieve acceptable air quality. This procedure prescribes the rate at which ventilation air must be delivered to a space and various means to condition that air. The ventilation rates in Table 3 are derived from physiological considerations, subjective evaluations and professional judgments.

The ***Indoor Air Quality Procedure*** (Section 6.2) provides an alternate performance method for achieving generally acceptable air quality. This procedure specifies maximum permissible concentrations of certain notable contaminants in indoor air but does not prescribe ventilation rates or air treatment methods.

6.1 VENTILATION RATE PROCEDURE: This procedure prescribes:

1. The outdoor air quality acceptable for ventilation;
2. Outdoor air treatment when necessary;
3. Ventilation rates for residential, commercial, institutional and industrial spaces;
4. Criteria for reduction of outdoor air quantities when recirculated air is treated by contaminant removal equipment;
5. Criteria for variable ventilation when the air volume in the space can be used as a reservoir to dilute contaminants.

6.1.1 *Acceptable Outdoor Air.* This section describes a four step procedure by which outdoor air shall be evaluated for acceptability:

Step 1: Contaminants in outdoor air do not exceed the concentrations listed in Table 1 as determined by one of the following conditions:

A. Monitoring data of government pollution-control agencies, such as the U.S. Environmental Protection Agency (EPA) or equivalent state or local environmental protection authorities, show that the air quality of the community in which the ventilating system is located meets the requirements of Table 1. Conformity of local air to these standards may be determined by reference to the records of local authorities or of the National Aerometric Data Bank, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, NC 27711.

B. The ventilating system is located in a community similar in population, geographic and meteorological setting and industrial pattern to a community having acceptable air quality as determined by local or national authorities.

C. The ventilating system is located in a community with a population of less than 20,000 people, and the

TABLE 1
NATIONAL AMBIENT AIR QUALITY STANDARDS*

Contaminant	Long Term		Short Term	
	Level	Time	Level	Time
Carbon Monoxide			40 mg/m^3	1 Hr
			10 mg/m^3	8 Hrs
Lead	1.5 μg/m^3	3 Mo		
Nitrogen Dioxide	100 μg/m^3	Yr		
Oxidants (Ozone)			235 μg/m^3	1 Hr
Particulates	75 μg/m^3	Yr	260 μg/m^3	24 Hrs
Sulfur Dioxide	80 μg/m^3	Yr	365 μg/m^3	24 Hrs

*See Reference 11. Pertinent local regulations should also be checked. Some regulations may be more restrictive than those given here, and additional substances may be regulated.

TABLE 2
ADDITIONAL AMBIENT AIR QUALITY GUIDELINES

Contaminant	Long Term		Short Term		Reference
	Level*	Time	Level	Time	
Acetone—O**	7 mg/m^3	24 Hrs	24 mg/m^3	30 Min	12
Acrolein—O			25 μg/m^3	C***	13
Ammonia—O	0.5 mg/m^3	Yr	7 mg/m^3	C	14.15
Beryllium	0.01 μg/m^3	30 Days			13
Cadmium	2.0 μg/m^3	24 Hrs			16
Calcium Oxide (Lime)			20-30 μg/m^3	C	17
Carbon Disulfide—O	0.15 mg/m^3	24 Hrs	0.45 mg/m^3	30 Min	12
Chlorine—O	0.1 mg/m^3	24 Hrs	0.3 mg/m^3	30 Min	12
Chromium	1.5 μg/m^3	24 Hrs			12
Cresol—O	0.1 mg/m^3	24 Hrs			13
Dichloroethane—O	2.0 mg/m^3	24 Hrs	6.0 mg/m^3	30 Min	12
Ethyl Acetate—O	14 mg/m^3	24 Hrs	42 mg/m^3	30 Min	12
Formaldehyde—O			120 μg/m^3	C	13
Hydrochloric Acid—O	0.4 mg/m^3	24 Hrs	3 mg/m^3	30 Min	12.15
Hydrogen Sulfide—O	40-50 μg/m^3	24 Hrs	42 μg/m^3	1 Hr	17 (7 states)
Mercaptans—O			20 μg/m^3	1 Hr	16
Mercury	2 μg/m^3	24 Hrs			16
Methyl Alcohol—O	1.5 mg/m^3	24 Hrs	4.5 mg/m^3	30 Min	12
Methylene	20 mg/m^3	Yr	150 mg/m^3	30 Min	14
Chloride—O	50 mg/m^3	24 Hrs			14
Nickel	2 μg/m^3	24 Hrs			16
Nitrogen Monoxide	0.5 mg/m^3	24 Hrs	1 mg/m^3	30 Min	14
Phenol—O	0.1 mg/m^3	24 Hrs			12.13
Sulfates	4 μg/m^3	Yr			17
	12 μg/m^3	24 Hrs			(4 states)
Sulfuric Acid—O	30 μg/m^3	Yr	200 μg/m^3	30 Min	14
	100 μg/m^3	24 Hrs			14
Trichlorethylene—O	2 mg/m^3	Yr	16 mg/m^3	30 Min	14
	5 mg/m^3	24 Hrs			
Vanadium	2 μg/m^3	24 Hrs			16
Zinc	50 μg/m^3	Yr			14
	100 μg/m^3	24 Hrs			14

* Unless otherwise specified, all air quality measurements should be corrected to standard conditions of 25°C (77 F) temperature and 760 mm. (29.92 inches) of mercury pressure. (101.3 kPa)
** These materials marked "O" have odors at concentrations sometimes found in outdoor air. The tabulated concentration levels do not necessarily result in odorless conditions.
***Ceiling, or maximum allowable concentrations.

air is not influenced by a source of substantial contamination.

D. Air monitoring for three consecutive months, as required for inclusion in the National Aerometric Data Bank, shows that the air quality meets or exceeds the requirements of Table 1.

Step 2: Outdoor air shall be considered unacceptable if it is known to contain any contaminant at a concentration above that listed in Table 2. This table covers other common contaminants for which no EPA ambient air quality standards exist. These levels were selected from current practices in various states, provinces and other countries.

Step 3: If the air is thought to contain any contaminant not listed in Tables 1 or 2, guidance on acceptable exposure levels should be obtained by reference to the standards of the Occupational Safety and Health Administration[18]. For application to the general population the concentration of these contaminants should not exceed 1/10 of the limits which are used in industry (see Appendix C). In some cases, this procedure may result in unreasonable limits. Expert consultation may then be required.

Step 4: If after completing steps 1, 2 and 3, there is still a reasonable expectation that the air is unacceptable, sampling shall be conducted in accordance with NIOSH procedures[19-20] Local and national aerometric data banks may contain information on some unregulated pollutants. Finally, acceptable quality should be evaluated using the definition in Section 3.1.

6.1.2 *Outdoor Air Treatment.* If the outdoor air contaminant levels exceed the values given in Section 6.1.1, the air shall be treated to control the offending contaminants. Filters suitable for the particle size encountered shall be used. For removal of gases and vapors, appropriate cleaning devices shall be used.

6.1.3 *Ventilation Requirements.* Indoor air quality shall be considered acceptable if the required rates of acceptable outdoor air in Table 3 are provided for the occupied space and no unusual indoor air contaminants are present. The table lists the required cfm (L/s) per person for a variety of indoor spaces. The contamination produced is presumed to be in proportion to the number of persons in the space. Where appropriate, the table lists the estimated density of people for design purposes. In residential applications, cfm (L/s) per room, regardless of size, is specified.

Higher ventilation rates are specified for spaces where smoking is permitted because tobacco smoke is one of the most difficult contaminants to control at the source. When smoking is allowed in occupied spaces, the amount of outdoor air required shall be determined by the "smoking" column of Table 3. However, any areas within those spaces which are designated "non-smoking" may have their outdoor air determined from the "non-smoking" column of Table 3, provided that air is not recirculated from, or otherwise enters from, the smoking areas.

A supply of outdoor air is necessary to dilute the CO$_2$ produced by metabolism and expired from the lungs. This value has been chosen as 5 cfm (rounded to 2.5 L/s) per person which allows an adequate factor of safety to account for health variations and some increased activity levels (see Appendix D). Therefore, outdoor air requirements shall never be less than 5 cfm (2.5 L/s) per person regardless of the treatment of the recirculated air (at this time no practical equipment exists to remove CO$_2$).

Exhaust air from one space sometimes can be used as supply air to another space where different contaminants are generated (corridors and office spaces exhausted through toilet rooms, or adjacent areas exhausted through autopsy rooms); this exhaust air shall then be considered equivalent to acceptable outdoor air.

In some cases, the number of persons cannot be estimated accurately or varies considerably. In other cases, a space may require ventilation to remove contamination generated within the space, but unrelated to human occupancy (e.g., outgassing from building materials or furniture). For these cases, Table 3 lists quantities in cfm/ft^2 (L/s · m^2) or an equivalent term. If human carcinogens or other harmful contaminants are suspected to be present in the occupied space, other relevant standards or guidelines (e.g., OSHA, NIH) must supersede the ventilation rate procedure.

When spaces are unoccupied, ventilation is not generally required. Ventilation may be required, however, to prevent accumulation of contaminants injurious to people, contents or structure.

6.1.4 *Recirculation Criteria.* The requirements for ventilation air quantities given in Table 3 are for 100% outdoor air when the outdoor air meets the specifications for air quality given in Tables 1 and 2. While these quantities are for 100% outdoor air, they also set the amount of air required to dilute contaminants to acceptable levels. Therefore, it is necessary that at least this amount of air be circulated at all times that the building is in use.

If proper air cleaners and adequate temperature control are provided, part of this air may be recirculated, but the outdoor air portion must never be less than 5 cfm (2.5 L/s) per person. The air cleaning system for the recirculated air may be located in the recirculated air stream or in the plenum which mixes the outdoor air and return air (see Figure 1).

The air cleaning system used to reclaim recirculated air shall be designed to remove particulate and gaseous contaminants. The required air cleaner efficiency and recirculation rate for the system shall be sufficient to provide an indoor air quality equivalent to that obtained using outdoor air as specified in Tables 1 and 2 and at a rate specified in Table 3. The air cleaner efficiency and recirculation rate shall be determined from the following equation (see Appendix E for rationale):

$$\dot{V}_r = \frac{\dot{V}_o - \dot{V}_m}{\varepsilon}$$

where

$\dot{V}_r$ = Recirculation rate (cfm or (L/s) per person).

$\dot{V}_o$ = Outdoor air rate specified in Table 3 for particular function (cfm or (L/s) per person).

$\dot{V}_m$ = The minimum rate of outdoor air that can be used in a recirculated air ventilating system to provide acceptable indoor air quality, but never less than 5 cfm (2.5 L/s) per person.

ε = Efficiency of contaminant removal (air cleaner) device. The efficiency should be derived from the most relevant parameters of the contaminants involved.

6.1.5 *Variable Occupancy.* Ventilating systems, for spaces with transient or variable occupancy, may have their outdoor air quantity adjusted by use of dampers, by stopping and starting the system, or by other means, to provide sufficient dilution to maintain contaminant concentrations within acceptable levels at all times. Such system adjustment may lag or should lead occupancy depending on the source of contaminants and the variation in occupancy.

When contaminants are associated only with occupants and are dissipated by natural means during unoccupied periods, supply of outdoor air may lag occupancy. When contaminants are generated in the space, independent of occupants or their activities, supply of outdoor air should lead occupancy so that acceptable conditions will exist at the start of occupancy. Figures 2 and 3 show lag or lead times needed to achieve acceptable conditions for transient occupancy (see Appendix F for rationale).

Ventilating systems also may be adjusted to compensate for variable occupancy when contaminants are associated only with the occupants. The appropriate

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION
3.1 Commercial Facilities (Offices, stores, shops, hotels, sports facilities, etc.)

	Estimated Occupancy, persons per 1000 ft² or 100 m² floor area. Use only when design occupancy is not known	Outdoor Air Requirements				
		Smoking	Non-smoking	Smoking	Non-smoking	Comments
Dry Cleaners and Laundries		cfm/person		L/s · person		
Commercial	10	—	15	—	7.5	A blank (—) indicates that smoking (or non-smoking) in a space should not occur.
Storage/pick-up areas	30	35	10	17.5	5	
Coin-operated Laundries	20	35	15	17.5	7.5	Dry cleaning processes may require more air
Coin-operated dry cleaning	20	—	15	—	7.5	
Food & Beverage Services						
Dining rooms	70	35	7	17.5	3.5	
Kitchens	20	—	10	—	5	
Cafeterias, fast food facilities	100	35	7	17.5	3.5	
Bars and cocktail lounges	100	50	10	25	5	
Garages, auto repair shops, service stations		cfm/ft² floor		L/s · m² floor		
Parking garages (enclosed)	—	1.5	1.5	7.5	7.5	Distribution must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal.
Auto Repair workrooms (general)	—	1.5	1.5	7.5	7.5	
Hotels, Motels, Resorts, Dormitories, & Correctional Facilities		cfm/room		L/s · room		See also food & beverage services, merchandising, barber & beauty shops, garages
Bedrooms (single, double)	5	30	15	15	7.5	Independent of room size
Living rooms (suites)	20	50	25	25	12.5	
Baths, toilets (attached to bedrooms)	*	50	50	25	25	Independent of room size; installed capacity for intermittent use.
		cfm/person		L/s · person		
Lobbies	30	15	5	7.5	2.5	
Conference rooms (small)	50	35	7	17.5	3.5	
Assembly rooms (large)	120	35	7	17.5	3.5	
Gambling Casinos	120	35	7	17.5	3.5	
Offices						
Office Space	7	20	5	10	2.5	
Meeting & waiting spaces	60	35	7	17.5	3.5	

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION (cont.)
3.1 Commercial Facilities (cont.)

	Estimated occupancy, persons per 1000 ft² or 100 m² floor area. Use only when design occupancy is not known.	Outdoor Air Requirements				Comments
		Smoking	Non-smoking	Smoking	Non-smoking	
Public spaces		cfm/ft² floor		L/s · m² Floor		
Corridors & utility rooms		0.02	0.02	0.10	0.10	
		cfm/stall or urinal		L/s · stall or urinal		
Public restrooms	100	75	—	37.5	—	
		cfm/locker		L/s · locker		
Locker & dressing rooms	30	35	15	17.5	7.5	
Retail Stores		cfm/person		L/s · person		
Sales Floors & Showrooms						
Basement & Street floors	30	25	5	12.5	2.5	
Upper floors	20	25	5	12.5	2.5	
Storage Areas (serving sales & storerooms)	15	25	5	12.5	2.5	
Dressing rooms	—	25	5	12.5	3.5	
Malls & arcades	20	10	5	5	2.5	
Shipping & receiving areas	10	10	5	5	2.5	
Warehouses	5	10	5	5	2.5	
Elevators	—	—	15	—	7.5	
Smoking rooms	70	50	—	25	—	
Specialty Shops		cfm/person		L/s · person		
Barber & Beauty shops	25	35	20	17.5	10	
Reducing salons, health spas (exercise rooms)	20	—	15	—	7.5	
Florists	10	25	5	12.5	2.5	Ventilation to optimize plant growth may dictate requirements.
Greenhouses	1	—	5	—	2.5	
Shoe repair shops (combined workrooms/ trade areas)	10	15	10	7.5	5	
		cfm/ft² floor		L/s · m² floor		
Pet shops	—	1	1	5	5	
Sports & Amusement Facilities		cfm/person		L/s · person		
Ballrooms & Discos	100	35	7	17.5	3.5	
Bowling alleys (seating areas)	70	35	7	17.5	3.5	When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates will be required.
Playing floors (e.g., gymnasiums, ice arenas)	30	—	20	—	10	
Spectator areas	150	35	7	17.5	3.5	
Game rooms (e.g., cards & billiards rooms)	70	35	7	17.5	3.5	
Swimming pools		cfm/ft² area		L/s · m² area		
Pool & deck areas	—	—	0.5	—	2.5	Higher values may be required for humidity control.
		cfm/person		L/s · person		
Spectators area	70	35	7	17.5	3.5	

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION (cont.)
3.1 Commercial Facilities (cont.)

	Estimated Occupancy, persons per 1000 ft² or 100 m² floor area. Use only when design occupancy is not known.	Outdoor Air Requirements				Comments
		Smoking	Non-smoking	Smoking	Non-smoking	
Theatres		cfm/person		L/s · person		
Ticket booths	—	20	5	10	2.5	
Lobbies, foyers, & lounges, & auditoriums in motion picture theatres, lecture, concert & opera halls	150	35	7	17.5	3.5	
Stages, TV & movie studios	70	—	10	—	5	Special ventilation will be needed to eliminate special stage effects (e.g. dry ice vapors, mists, etc.)
Transportation						
Waiting rooms, ticket & baggage areas, corridors & gate areas, platforms, concourses	150	35	7	17.5	3.5	Ventilation within vehicles will require special consideration.
Workrooms		Cfm/person		L/s · person		
Meat processing rooms	10	—	5	—	2.5	Spaces maintained at low temperatures (-10 F to +50 F, or -23°C to +10°C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement. (See Ref 21)
Pharmacists' workroom	20	—	7	—	3.5	
Bank vaults	10	—	5	—	2.5	
Photo studios						
Camera room, stages	10	—	5	—	2.5	
Darkrooms	10	—	20	—	10	
		cfm/ft² floor		L/s · m² floor		
Duplicating & printing rooms		—	0.5	—	2.5	Installed equipment must incorporate positive exhaust & control (as required) of undesirable contaminants (toxic or otherwise).
Educational Facilities		cfm/person		L/s · person		
Classrooms	50	25	5	12.5	2.5	
Laboratories	30	—	10	—	5	Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shops	30	35	7	17.5	3.5	
Music rooms	50	35	7	17.5	3.5	
Libraries	20	—	5	—	2.5	

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION (cont.)
3.2 Institutional Facilities (cont.)

	Estimated occupancy, persons per 1000 ft^2 or 100 m^2 floor area. Use only when design occupancy is not known.	Outdoor Air Requirements				Comments
		Smoking	Non-smoking	Smoking	Non-smoking	
Hospital, Nursing & Convalescent Homes						Special requirements or codes and pressure relationships may determine minimum ventilation rates and filter efficiency.
		cfm/bed		L/s · bed		
Patient rooms	10	35	7	17.5	3.5	
		cfm/person		L/s · person		
Medical procedure areas	10	35	7	17.5	3.5	
Operating rooms, delivery rooms	20	—	40	—	20	Procedures generating contaminants may require higher rates.
Recovery & intensive care rooms	20	—	15	—	7.5	
Autopsy rooms	20	—	100	—	50	Air shall not be recirculated into other spaces.
Physical therapy areas	20	—	15	—	7.5	

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION (cont.)
3.3 Residential Facilities (Private dwelling places, single or multiple, low or high rise)

	Outdoor Air Requirements		Comments
			Operable windows or mechanical ventilation systems shall be provided for use when occupancy is greater than usual conditions or when unusual contaminant levels are generated within the space.
	cfm/room	L/s · room	
General living areas	10	5	Ventilation rate is independent of room size
Bedrooms	10	5	
All other rooms	10	5	
Kitchens	100	50	Installed capacity for intermittent use
Baths, toilets	50	25	
	cfm/car space	L/s · car space	
Garages (separate for each dwelling unit)	100	50	
	cfm/ft^2 floor	L/s · m^2 floor	
Garages (common for several units)	1.5	7.5	

Table 3 OUTDOOR AIR REQUIREMENTS FOR VENTILATION (cont.)
3.4 Industrial Facilities

Occupational safety laws in various states usually regulate process ventilation requirements. The following list gives the requirements for the occupants only, assuming that the ventilated air is of a quality equal to or exceeding all limits listed in Section 6.1. Air of this quality may be included as part of the process ventilation.

	Outdoor Air Requirements				Comments
	Smoking	Non-smoking	Smoking	Non-smoking	
	cfm/person		L/s · person		
High Activity level (2.5 met)*	35	20	17.5	10	Mining, foundry, etc.
Medium Activity level (2.0 met)	35	10	17.5	5	Automotive repair, assembly line, etc.
Low activity level (1.5 met)	35	7	17.5	3.5	Laboratory work, light assembly, etc.

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*1.0 met = sedentary activity level = 18.4 Btu/hr · ft^2 body surface (58.2 W/m^2).

ventilation rates, which may be calculated by a method similar to those described in Appendix F, shall be determined by the designer. The effectiveness of this system adjustment shall be demonstrated.

6.2 INDOOR AIR QUALITY PROCEDURE: The ventilation rate procedure described above is assumed to provide acceptable indoor air quality, *ipso facto*. Nevertheless, that procedure, through prescription of required ventilation rates, provides only an indirect solution to the control of indoor contaminants. A direct solution would bring the concentrations of contaminants to some specified, acceptable levels. The indoor air quality procedure, described below, provides guidelines for certain notable contaminants. It incorporates both objective measurement and subjective evaluation.

6.2.1 *Objective Measurement.* Tables 1 and 2 furnish information on acceptable contaminant levels in outdoor air. These tables also apply indoors for the same exposure times. Section 6.1.1. contains additional information on contaminants.

In recent years, problems have arisen from contaminants unrelated to occupancy, but rather generated by the building itself and its contents. Examples include asbestos dust, radon gas, and vapors of formaldehyde

PROCEDURE

a. Compute the air capacity per person in the space in ft^3 (m^3).
b. Find the required ventilation rate, in cfm (L/s) per person.
c. Enter Figure 2 with these values and read the maximum permissible ventilation lag time after occupancy from the intersection of a and b.

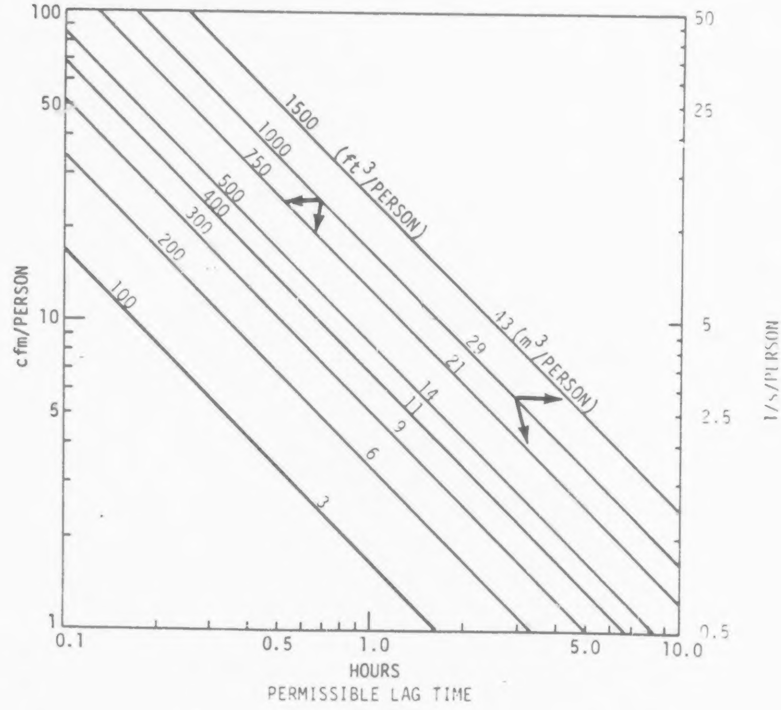

Figure 2. Maximum Permissible Ventilation Lag Time

and mercury. Other contaminants of this type will undoubtedly be identified and will require attention. Where a regulation of notable indoor contaminants has been developed, it is included in Table 4. Uniform governmental policies regarding limits on exposure to environmental carcinogens have not yet emerged. Employment of the best available control technology is frequently recommended and is noted in Table 4 where relevant.

There remain several indoor contaminants not covered by the discussion above. These are poorly characterized complex mixtures such as tobacco smoke, infectious and allergic biologic aerosols, and emanations from human bodies and from food preparation. Precise quantitative treatment of these contaminants can be difficult. To some degree, adequacy of control must rest upon subjective evaluation, discussed below. In the case of biologic aerosols, subjective evaluation is largely irrelevant. Application of generally acceptable technology, and vigilance regarding adverse influences of reduced ventilation, must therefore suffice.

6.2.2 *Subjective Evaluation.* Various indoor activities may give rise to odor of unacceptable intensity or character, or to airborne materials that irritate the eyes,

PROCEDURE

a. Compute the air capacity per person in the space in ft^3 (m^3).
b. Find the required ventilation rate, in cfm (L/s) per person.
c. Enter Figure 3 with these values and read the minimum required ventilation lead time before occupancy from the intersection of a and b.

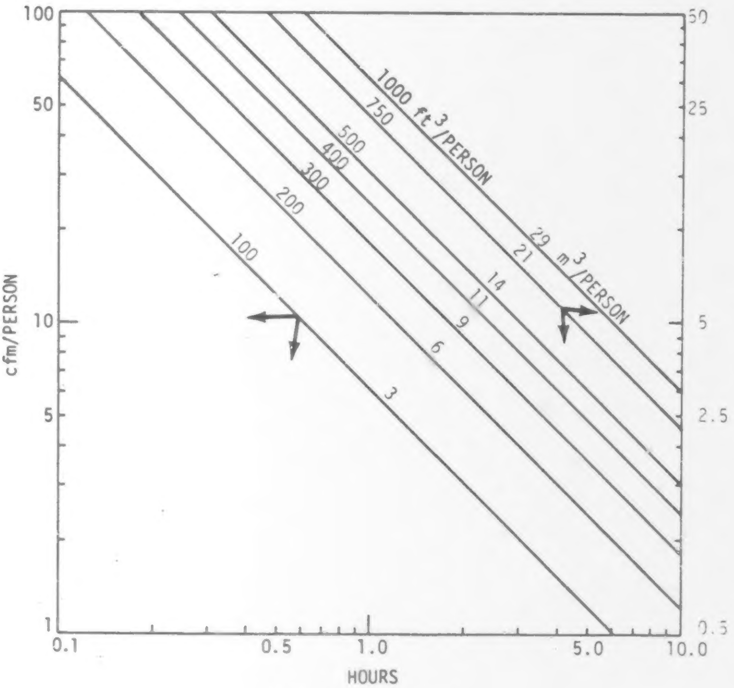

Figure 3. Minimum Ventilation Time Required Before Occupancy of Space

TABLE 4
SELECTED GUIDELINES FOR AIR CONTAMINANTS OF INDOOR ORIGIN

Contaminant	Concentrations**	Exposure Time	Comments
Acetone—O*			
Ammonia—O			
Asbestos			Known human carcinogen, best available control technology.
Benzene—O			Known human carcinogen, best available control technology.
Carbon Dioxide	4.5 g/m³	Continuous	See Appendix D
Chlordane—O	5 µg/m³	Continuous	Reference 22
Chlorine			
Cresol—O			
Dichloromethane—O			
Formaldehyde—O	120 µg/m³	Continuous	W. German and Dutch Guidelines
Hydrocarbons, Aliphatic—O			
Hydrocarbons, Aromatic—O			
Mercury			
Ozone—O	100 µg/m³	Continuous	Reference 23
Phenol—O			
Radon	0.01 Working Level (WL)	Annual average	Reference 24 Paragraph 12.6 (background 0.002-0.004 WL)
Tetrachloroethylene—O			
Trichloroethane—O			
Turpentine—O	–		
Vinyl Chloride—O			Known human carcinogen, best available control technology.

* These materials marked "O" have odors at concentrations sometimes found in indoor air. The tabulated concentrations do not necessarily result in odorless condi

** Where concentrations are lacking refer to Section 6.1.1, Step No. 3. These substances are ones for which indoor exposure standards are not yet available.

nose, or throat. In an absence of objective means to assess the acceptability of such contaminants, the judgment of acceptability must necessarily derive from subjective evaluations of impartial observers. The air can be considered acceptably free of annoying contaminants if 80% of a panel of at least 20 untrained observers deems the air to be not objectionable under representative conditions of use and occupancy. An observer should enter the space in the manner of a normal visitor and should render a judgment of acceptability within 15 seconds. Each observer should make the evaluation independently of other observers and without influence from a panel leader.

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APPENDIX A

CONVERSION FACTORS
Parts per million and Mass per unit volume

Measurement of airborne concentration of substances is generally converted to 25°C (77 F) and 760 mm Hg (29.92 in. Hg) pressure. Vapors or gases are often expressed as parts per million (ppm) by volume and are also frequently expressed in units of mass per unit volume, commonly in the following units:

milligram per cubic meter (mg/m^3); microgram per cubic meter ($\mu g/m^3$); milligram per cubic foot (mg/ft^3); grains per cubic foot (gr/ft^3).

Knowing the specific gravity of a vapor or gas relative to air, the ppm values may be converted to mass per unit volume values as follows, respectively[25]

$$\text{ppm} \times \frac{\text{Molecular weight}}{24{,}450} = \text{mg/liter}$$

$$\text{ppm} \times \frac{\text{Molecular weight}}{24{,}450} \times 10^6 = \mu\text{g/m}^3$$

$$\text{ppm} \times \frac{\text{Molecular weight}}{24{,}450} \times 10^3\ \text{mg/m}^3$$

$$\text{ppm} \times \frac{\text{Molecular weight}}{24{,}450} \times 28.3 = \text{mg/ft}^3$$

$$\text{ppm} \times \frac{\text{Molecular weight}}{24{,}450} \times \frac{28.3}{64.8} = \text{gr/ft}^3$$

Airborne particle count concentrations measured in million particles per cubic foot (mppcf) or million particles per cubic meter (= particles per cubic centimeter) can be converted approximately to mass per unit volume as follows when density and mass median diameter have not been determined:

$$\text{mppcf} \times 6 \text{ approx.} = \text{mg/m}^3$$

$$\text{particles per cc} \times 210 \text{ approx} = \text{mg/m}^3$$

APPENDIX B

POSITIVE COMBUSTION AIR SUPPLY

Atmospheric gas-fired appliances equipped with an open draft hood for control of combustion chamber draft must exhibit a positive flow of air into the draft hood whenever combustion is present. Measurements should be made when building infiltration is low i.e., the inside-outside temperature difference should be no more than 18°C (30 F) and wind

velocity is no more than 2.2 m/s (5 mph). Commonly used exhaust fans such as kitchen and bathroom exhaust fans should be turned on. Flow of room air into the draft hood under these conditions must indicate a 40% dilution[26] of the products of combustion going up the stack. This can be measured by measuring the room air temperature entering the draft hood, the stack temperature downstream from the draft hood, and the flue temperature at the combustion chamber outlet just upstream of the draft hood before the draft hood dilution air cools the flue gas.
Then

$$\frac{T_f - T_s}{T_s - T_r} = 0.40$$

T_f = Flue Temperature
T_s = Stack Temperature
T_r = Room Temperature

If the stack temperature exceeds

$$T_s = \frac{T_f + 0.4\,T_r}{1.4}$$

under the measurement conditions defined above, a positive supply of outside combustion air is needed for safe operation of the furnace.

Power burners of the type used in oil burners have a blower to supply combustion air. There must be enough air supplied to this type of burner to assure that the burner blower produces the pressure rise specified by the manufacturer. If a building is so tight that the blower cannot achieve its rated pressure rise, a positive supply of outdoor air must be provided. Care must be exercised with oil burners, however, if cold outdoor air is ducted directly to the burner, the low air temperature may degrade atomization and burner efficiency. The outdoor air provided should be temporary heat loss from the stack and furnace jacket.

APPENDIX C

RATIONALE FOR THE USE OF INDUSTRIAL STANDARDS OF EXPOSURE TO TOXIC AND HAZARDOUS SUBSTANCES

Industrial health practice attempts to limit worker exposure to injurious substances at levels which do not interfere with the work process, and which do not injure the workers' health. The elimination of all effects, e.g., unpleasant smells or mild irritation, is not attempted. Regulations are based on the results of accumulated experience with worker health, and of animal experiments, carefully evaluated by groups of competent experts. Exposure and effects are related to dose of the injurious substance. Dose includes both the concentration of the substance and the time during which it is present. Since concentration commonly varies with time, dose is conveniently expressed as a time weighted averge concentration (TWA), or threshold limit value (TLV). OSHA regulations are TWA's in most cases. These are explained with examples in the introduction to the reference tables[18]. With some substances severe reaction may be present at certain exposure concentrations. Where this occurs a ceiling (C), or maximum allowable concentration (MAC), is imposed in addition to the TWA so that upward excursions in the exposure concentrations can be kept below the critical level. Industrial exposures are regulated on the basis of a forty hour work week with 8 to 10 hour work days. The remainder of the time will be free of this exposure. Since public exposure to air contaminants may be continuous rather than limited to 40 hours per week, the TWA should be lowered in recognition of this difference. The work time exposure is approximately 1/5 of the hours in a year; therefore, the allowable concentration for the general public should first be reduced to 1/5 of its value. In addition, a further reduction to 1/10 is desirable because (1) the general population is more varied than the industrial population in susceptibility to injury due to greater variation in age and in health status, and (2) the industrial population is often under continual health supervision and the general population may not be.

APPENDIX D

RATIONALE FOR MINIMUM PHYSIOLOGICAL REQUIREMENTS FOR RESPIRATION AIR BASED ON CO_2 CONCENTRATION

Oxygen is necessary for metabolism of food to sustain life. Carbon and hydrogen in foods are oxidized to CO_2 and H_2O which are eliminated by the body as waste products. Foods can be classified as carbohydrates, fats or proteins and the ratio of carbon to hydrogen in each is somewhat different. The Respiratory Quotient (RQ) is the volumetric ratio of carbon dioxide to the oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.80 for a diet of 100% protein and 1.0 for a diet of 100% carbohydrate[27]. A value of RQ = 0.83 applies to the normal mix of fat, carbohydrate and protein.

The O_2 required depends upon the activity level. At sedentary activity level, the O_2 requirement is 0.0125 cfm. If we assume a person can consume 25% of the O_2 in air, then, since air is about 21% O_2, the air required for oxygen supply is [0.0125/(0.21)(0.25)] = 0.24 cfm, clearly a small amount. There is no problem dissipating the H_2O produced by metabolism.

The controlling physiological factor is the CO_2 concentration in the inhaled air, not the O_2 limitation. People can function at levels of CO_2 as high as 1% (as in nuclear submarines), but it is generally felt that 0.5% is a better limit (symptoms of high CO_2 levels are headaches and loss of judgment). If 0.5% CO_2 is taken as the limit, then

CO_2 (inspired) = CO_2 (outdoor air) + $\dot{N}/V$
where CO_2 (outdoor) $\simeq$ 0.03%
$\dot{N}$ = generation rate of CO_2 = 0.63 ft^3/hr per person
V = ventilation rate ft^3/hr per person
CO_2 (inspired) = % concentration
CO_2 (inspired) = [CO_2 (outdoor) + (0.63 × 100) (cfm × 60)]
= [CO_2 (outdoor) + 1.05/cfm]

Solving the equation when CO_2 is 0.5% and lower results in the following table for the required ventilation rate of outdoor air per person at a sedentary activity level.

%CO_2 Limit	cfm/person
0.5	2.25
0.4	2.86
0.3	3.92
0.25	5.00
0.2	6.23
0.1	15.10

For general ventilation standards, a limit value of CO_2 in the air is taken as about 0.25% as an additional safety factor, covering individual activity, diet and health variations. The minimum outdoor air requirement is then 5 cfm/person, and this standard specifies that minimum. This must be supplied from sources outside the space, where CO_2 levels are near 0.03% (as in outdoor air). The cfm/person is linear with metabolic level for the same CO_2 level, and correspondingly higher limits are needed where activity is greater than sedentary air volume per person is also linear with RQ. The effect of altitude is small, and no correction is considered necessary to 7,000 feet, that being well within the safety factor. (An altitude or pressure correction table should be included for high altitudes and special chambers.)

APPENDIX E

RATIONALE FOR USE OF CLEANED, RECIRCULATED AIR

Two methods of controlling indoor air quality within acceptable concentrations are dilution and air cleaning. The dilution method may be used by providing outdoor air, at a quality specified in Tables 1 and 2, to occupied spaces at rates specified in Table 3. For energy conservation purposes, the air cleaning method may be used by providing sufficient quantities of treated recirculated air to maintain the indoor air at a quality equivalent to that provided by the dilution method. This alternative method requires that both the recirculation rate and the contaminant removal efficiency be specifiied. A simplified form of this relationship, specified in section 6.1.4, is derived in the following paragraphs.

The steady-state mass balance for the 100% outdoor air system, shown in Figure E-1, may be expressed as:

$$\dot{V}_o (C_s - C_o) = \dot{N} \qquad \text{(E-1)}$$

For the recirculated air system with the air cleaner in the return air, Figure E-2, the expression may be written as:

$$\dot{V}_m C_o \times (1 - \varepsilon)\dot{V}_r C_s + \dot{N} = (\dot{V}_r + \dot{V}_m) C_s \qquad \text{(E-2)}$$

and, for the recirculated air system with the air cleaner in the mixed air, Figure E-3, the expression may be written as:

$$(\dot{V}_m C_o + \dot{V}_r C_s)(1 - \varepsilon) + \dot{N} = (\dot{V}_r + \dot{V}_m) C_s \qquad \text{(E-3)}$$

where:

$\dot{V}_o$ =Required ventilation rate of 100% outdoor air which meets specifications in Sections 3 and 6* (cfm or (L/s) per person.)

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*$\dot{V}_o$ also includes infiltration air

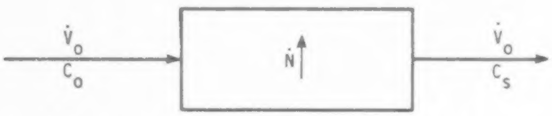

Fig. E-1 100 PERCENT OUTDOOR AIR

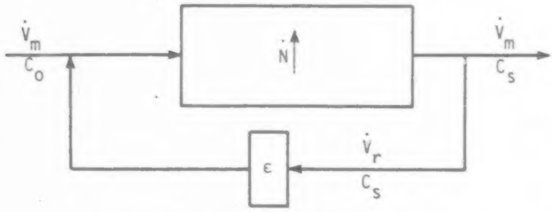

Fig. E-2 FILTER IN RECIRCULATED AIR

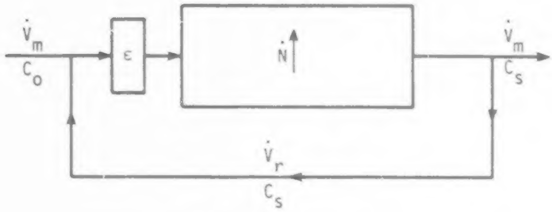

Fig. E-3 FILTER IN MIXED AIR

$\dot{V}_m$ =The reduced or minimum rate of outdoor air that can be used in a recirculated air ventilating system to provide acceptable indoor air quality, but never less than 5 cfm (2.5 L/s) per person.
$\dot{V}_r$ =Recirculated air flow rate (cfm or (L/s) per person).
C_o =Contaminant concentration in outdoor air ($\mu g/m^3$).
C_s =Contaminant concentration in occupied space ($\mu g/m^3$).
$\dot{N}$ =Net production rate of contaminant per unit volume in occupied space, in dimensions consistent with concentration ($\mu g/m^3 min.$)
ε =Contaminant removal efficiency, dimensionless, rated in the same terms or parameters as the contaminant (e.g., percent removal by mass of 0.5 to 1.0 μm particles.

Since the recirculated air systems are assumed to provide indoor air equivalent to the outdoor air system, the net production rate described by Equation (1) may be substituted into Equation (2) and Equation (3):

$$\dot{V}_m\left(\frac{C_o}{C_s}\right) + (1-\varepsilon)\dot{V}_r + \dot{V}_o\left(1\ \frac{C_o}{C_s}\right)$$
$$= (\dot{V}_m + V_r) \tag{E-2a}$$

and

$$\left[\dot{V}_m\left(\frac{C_o}{C_s}\right) + \dot{V}_r\right](1-\varepsilon) + \dot{V}_o\left(1 - \frac{C_o}{C_s}\right)$$
$$= (\dot{V}_m + \dot{V}_r) \tag{E-3a}$$

Under normal conditions, the concentrations of contaminants in the outdoor air will be much less than the concentrations specified in Tables 1 and 2. It is also reasonable to assume that the normal concentrations indoors will exceed those outdoors. So, the values of C_o/C_s in Equation (2a) and Equation (3a) may often be assumed to be negligible. For these cases, Equation (2a) and Equation (3a) simplifiy to:

$$\dot{V}_r = \frac{\dot{V}_o - \dot{V}_m}{\varepsilon} \tag{E-4}$$

This is the form of the equation cited in Section 6.1.4. In this form, the recirculation rate for a given efficiency will be estimated conservatively high (e.g., for $\varepsilon = 0.8$, $\dot{V}_r$ will be estimated 10 to 20% higher than a more rigorous solution would provide). However, if the indoor concentration is critical or if the outdoor air concentrations are near the concentrations reported in Tables 1 and 2, the recirculation rates and -contaminant removal efficiencies should be determined from the more rigorous forms of Equation (E-2) or Equation (E-3).

As an example of this method and its limitations, consider a meeting and waiting space in an office where smoking is allowed. Table 3 indicates that a ventilation rate of 35 cfm per person would be required if acceptable indoor air quality were to be maintained. However, only 7 cfm per person would be required if smoking were not allowed. If an air cleaner were rated at 90% removal efficiency for tobacco smoke particulates, and the outdoor air concentration of total suspended particulates were negligible, what would be the required recirculation rate and supply rate if the outdoor rate were reduced from 35 to 7 cfm per person?

From Equation (E-4): $\dot{V}_r = \frac{35 - 7}{0.9} = 31$ cfm per person

Thus, the total supply rate ($\dot{V}_r + \dot{V}_m$) would be 38 cfm per person rather than 35 cfm per person outdoor air, but only 7 cfm per person would be outdoor air; a reduction of 80%.

If the total suspended particulate concentration of the outdoor air were suspected to be near the maximum concentration of 75 μg TSP/m^3 and the indoor concentration were not to exceed 260 μg TSP/m^3, the recirculation rate can be determined from Equation (E-3a):

$$[7(0.288) + \dot{V}_r][0.1] + 35(1 - 0.288) = 7 + \dot{V}_r$$

$$\dot{V}_r = 20 \text{ cfm per person}$$

and, $(\dot{V}_r + \dot{V}_m) = 27$ cfm per person, compared to the originally specified value of 35 cfm per person. Thus, conditions exist in which recirculation air can allow reduction of outdoor air for energy conservation and may produce an improved indoor air quality relative to the dilution method.

APPENDIX F

RATIONALE FOR LAG OR LEAD TIME FOR TRANSIENT OCCUPANCY

When spaces such as classrooms, auditoriums, or offices are unoccupied for several hours and then occupied, operation of the ventilation system may be delayed to use the cpaacity of the air in the space to dilute contaminants. This applies to cases where the inside contaminants are associated only with human occupancy and where contaminants are dissipated by natural means during long vacant periods. The operation of the ventilation system can then be delayed until the concentration of contaminants reaches the acceptable limit associated with the minimum ventilation requirements at steady state.

The concentration of any contaminant C in the absence of ventilation in a given space of volume V is expressed as follows:

$$C_\Theta = \frac{\dot{N}}{V}\Theta \tag{F-1}$$

where $\dot{N}$ is the contaminant generation rate and Θ is time. The contaminant concentration C_s under a steady state condition with ventilation rate $\dot{V}$ is:

$$C_s = \frac{\dot{N}}{\dot{V}} \tag{F-2}$$

The maximum permissible ventilation delay time after the space is occupied is when C_Θ equals C_s or:

$$\Theta = \frac{V}{\dot{V}} \tag{F-3}$$

This equation is plotted in Figure 2 for various ventilation rates in cfm/person (l/s · person) and space volume in ft^3/person (L/person).

When contaminants are generated independent of people or their activities, and the contaminants do not present a short-term health hazard, ventilation may be shut off during unoccupied periods. In these cases, however, ventilation must be provided in advance of the time of occupancy, so that acceptable conditions will exist for people at the start of occupancy. It is impractical to operate the ventilation at the minimum requirement until steady-state is reached, because this is approached asymptotically with time, and may take several hours to reach practical equilibrium. An engineering estimate of a permissible contaminant level of 1.25 times the steady- state value has therefore been selected as the maximum level at the time of occupancy. The occupants would, for a time, be subjected to somewhat higher values of contaminant than the steady-state value. It is postulated that the factor of safety implicit in the values in Section 6.1.3 are adequate so that, for practical purposes, the required air quality is provided over the entire occupancy period.

When an initially contaminated room with a level of concentration C_i is diluted by a given rate of ventilation $\dot{V}$, the time required to lower the concentration to a fraction X above the final steady-state concentration level can be expressed as follows:

$$\Theta = \frac{V}{\dot{V}} \ln\left[\frac{(C_i \dot{V}/\dot{N}) - 1}{X} \right] \qquad \text{(F-4)}$$

where

V = Room volume
Θ = Time
$\dot{N}$ = Contaminant concentration generation rate
$\dot{V}$ = Ventilation rate
C_i = Initial concentration

Figure 3 is a plot of this relationship where C_i is assumed to be approximately 10 times the steady-state value and X = 0.25 or 25%.

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effects on the indoor and outdoor environment of the systems and components in their responsibility, while maximizing the beneficial effects which these systems provide, consistent with the accepted standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor or outdoor environment to a greater extent than specified by the standards as established by itself and other responsible bodies.

As an on-going goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards where appropriate and adopt, recommend and promote those new and revised standards developed by other responsible organizations.

Through its Handbook, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with research and dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations which is pertinent, as guides to updating standards.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use, and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

ASHRAE STANDARDS

ASHRAE Standards are updated on a five-year cycle; the date following the Standard number is the year of approval. The latest copies of ASHRAE Standards may be purchased from the ASHRAE Circulation Sales Department, 1791 Tullie Circle,N.E. Atlanta,GA 30329. Postage and handling: U.S. add $.35 for each individual copy, $2.00 for full set; foreign add $.65 for each individual copy, $3.00 for full set. Remittance required with order.

Standards approved by the American National Standards Institute are designated ANSI.

	PRICES M	PRICES NM
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14-67 Condensing Units, Positive Displacement, Mechanical, Methods of Testing for Rating	$ 2.25	$ 4.50
14-80 Positive Displacement Condensing Units, Methods of Testing for Rating	$ 3.00	$ 6.00
15-78 (Supersedes 15-70 ANSI B9.1-1971) Safety Code for Mechanical Refrigeration	$ 2.50	$ 5.00
16-69 Room Air Conditioners, Method of Testing for Rating	$ 4.00	$ 8.00
17-75 Expansion Valves, Refrigerant, Method of Rating and Testing (ANSI B60.1-1975)	$ 5.00	$10.00
18-79 (Supersedes 18-62) Drinking Water Coolers with Self Contained Mechanical Refrigeration Systems, Methods of Testing for Rating	$ 2.00	$ 4.00
20-70 (Supersedes 20-60) Remote Mechanical Draft Air-Cooled Refrigerant Condensers, Method of Testing for Rating	$ 2.50	$ 5.00
22-78 (Supersedes 22-71) Water-Cooled Refrigerant Condensers, Methods of Testing for Rating	$ 2.50	$ 5.00
23-78 Positive Displacement Refrigerant Compressors, Methods of Testing for Rating	$ 2.75	$ 5.50
24-78 (Supersedes 24-71) Liquid Coolers, Methods of Testing for Rating	$ 5.00	$10.00
25-77 (Revised 25-58) Forced Convection and Natural Convection Air Coolers for Refrigeration, Methods of Testing for Rating	$ 2.25	$ 4.50
26-78 Mechanical Refrigeration Installations on Shipboard. Updated and revised from Standard 26-66 (ANSI B59.1-64)	$ 3.00	$ 6.00
28-78 (Supersedes 28-72) Capillary Tubes, Method of Testing	$ 2.00	$ 4.00
29-78 (Supersedes 29-71) Automatic Ice Makers, Methods of Testing	$ 2.00	$ 4.00
30-78 Liquid Chilling Packages, Methods of Testing for Rating	$ 2.00	$ 4.00
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33-78 Forced Circulation Air-Cooling Coils (under non-frosting conditions) and Air-Heating Coils, Methods of Testing for Rating; includes forms for recording coil physical data, test and calculations	$ 6.00	$12.00
34-78 Number Designation of Refrigerants (Supersedes ANSI B79.1-1968)	$ 2.50	$ 5.00
35-78 (Supersedes 35-68) Desiccants for Refrigerant Drying, Methods of Testing	$ 2.00	$ 4.00
37-78 Unitary Air-Conditioning & Heat Pump Equipment, Methods of Testing for Rating	$ 6.00	$12.00
40-80 Heat Operated Unitary Air-Conditioning Equipment for Cooling, Methods of Testing for Rating	$ 2.50	$ 5.00
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41.4-75 Standard Method of Measurement of the Proportion of Oil in Liquid Refrigerants	$ 2.00	$ 4.00
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41.7-78 Standard Method of Measurement of Flow of Gases	$ 2.00	$ 4.00
41.8 (41.7.2) Standard Measurement of Flow of Liquids	$ 2.50	$ 5.00
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52-76 Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter, Method of Testing* (Supersedes 52-68)	$ 3.00	$ 6.00
55-74 Thermal Environmental Conditions for Human Occupancy (ANSI B193.1-1976)	$ 5.00	$10.00
58-74 Room Air Conditioner Heating Capacity, Method of Testing for Rating	$ 3.00	$ 6.00
62-1981 Ventilation for Acceptable Air [illegible]	$ 4.00	$ 8.00
63-75 Liquid Line Refrigerant Driers, Method of Testing	$ 2.00	$ 4.00
64-74 Remote Mechanical-Draft Evaporative Refrigerant Condensers, Methods of Testing	$ 3.00	$ 6.00
68-78 Method of Testing Sound Power Radiated into Ducts from Air Moving Devices	$ 2.00	$ 4.00
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70-72 Air Flow Performance of Outlets & Inlets, Method of Testing for Rating	$ 2.50	$ 5.00
71-73 Unit Ventilators, Method of Testing for Rating	$ 5.00	$10.00
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91-76 (Supersedes 91-73) Methods of Testing for Rating Pre-Mix and Post-Mix Soft Drink Vending and Dispensing Equipment	$ 2.00	$ 4.00
93-77 Methods of Testing to Determine Thermal Performance of Solar Collectors (ANSI B198.1-1977)	$ 4.00	$ 8.00
94-77 Methods of Testing Thermal Storage Devices Based on Thermal Performance (ANSI B198.1-1977)	$ 3.00	$ 6.00
93-94 Combination Price	$ 5.00	$10.00
96-80 Methods of Testing to Determine the Thermal Performance of Unglazed Flat-Plate Liquid-Type Solar Collectors	$ 4.00	$ 8.00

*27 Construction Drawings for ASHRAE STANDARD 52-76 describe how to apply the methods outlined in the Standard to the building of apparatus for testing air cleaning devices. The set $25.00. Postage: add $1.00 for U.S. and $2.00 for foreign.

Mr. **Fuqua**. Thank you very much, Dr. Woods, and all of our panel.

Dr. Woods, you stated in your testimony that patterns of air movement within occupied spaces are as important as specifying and controlling the rate of supply of air to these spaces.

What do you mean by that and what kind of research would it take to better understand air movement patterns within occupied spaces?

Dr. **Woods**. From an engineering standpoint, the standards that have been developed over history are either—they specify ventilation rates based on CFM per person or air changes per hour. Those are the two basic ways that the ventilation rates are specified.

The assumption is if that air is brought into the space, that that is the condition of the air the people will breathe. Technically what that amounts to is assuming that the air within that occupied space will be uniformly mixed. In fact, we find that the air very seldom is uniformly mixed. And therefore, what the occupant is exposed to at his position may be very different than the condition that would be measured in the supply air or the condition that would be measured in the return air.

There are techniques that are being developed now, and I mentioned a couple of these—the ventilation efficiency and their relative exposure index—that begin to give us some indication of the amount of mixing that occurs in that space or the uniformity of the air that is in that space.

It is an extremely complicated problem and very little is known about the modeling techniques. I think on an international basis there may be two or three models that have been two or three models that have been proposed in three dimensions that would allow prediction of this nonuniformity.

So I think much effort is needed to be able both mathematically and physically to develop our data base so that we can see from a predictive standpoint and then for design purposes what could be done to assure that the air that the people are breathing—that the air the people breathe is the type of air that is supplied to the space, or if there is a difference, that we could predict what the difference would be.

Mr. **Fuqua**. Dr. Moschandreas, what are your findings on the indoor pollution levels associated with wood stoves and are they—are they serious?

Dr. **Moschandreas**. We did 40 residences. We measured 40 residences. Of the 40 residences——

Mr. **Fuqua**. Now is this—and maybe you will outline—was this open fireplaces or stoves?

Dr. **Moschandreas**. We measured both fireplaces and wood stoves. I do not recall the exact portion of wood stoves versus fireplaces, but of the 40 residences we measured, about five indicate elevated levels of benzo-a-pyrene.

As I pointed out, I am not a health expert. However, I have been told again and again and again that benzo-a-pyrene is carcinogenic. The levels were much higher than the outdoor levels.

Mr. **Fuqua**. Now was that associated with a particular type of wood that was being used or——

Dr. **Moschandreas**. We were controlling the wood that we used. We used one type of wood. We believe subsequent to that study—currently right now we are performing studies where we control the experiment totally. We do the burning under perfect conditions, exactly as it is supposed to be.

In all of the experiments that we have performed so far, we find no elevation of any indoor pollutants under correct conditions. Now, when we close the—we reduce the florate through the stack, we find out that both particulate matter as well as polynuclear aromatic hydrocarbons increase.

Therefore, we believe that under correct conditions wood burning should not cause any concern. These are preliminary results. Under conditions that I understand occur once in a while—and I don't know how often—that wood burning should cause concern.

Mr. **Fuqua**. What kind of conditions would those be?

Dr. **Moschandreas**. Climatic conditions, I suppose. When the air flow, rather than going up, it starts coming down. When—I have a fireplace——

Mr. **Fuqua**. Yeah, but then you want to open the door and get out.

Dr. **Moschandreas**. That is about the extent of it. I have—I have a fireplace, and I would guess once every six or seven times when we start it we have an incident of increased smoke. That incident of increased smoke is associated with elevated benzo-a-pyrene levels.

Dr. **Spengler**. May I elaborate on that?

Mr. **Fuqua**. Yes.

Dr. **Spengler**. John Spengler.

We conducted a study in a wood-burning community in Vermont two winters ago, and I agree completely that under—and it seems like the people in Vermont knew how to burn wood in their wood airtight stoves, but you would—you encountered several other kinds of problems. Clearly the outdoor air was highly polluted in a valley setting.

Dr. **Moschandreas**. Absolutely.

Dr. **Spengler**. This has happened across the United States. So it is most prominently an outdoor problem. That air circulates back into a house. It comes from somewhere. It comes from the outdoor back into a house, so it brings those contaminants back in.

What we have found in a couple of cases——

Mr. **Fuqua**. There again, that would depend on weather conditions outside, too, as to whether it was hanging in there or going on——

Dr. **Spengler**. That's right. It is mostly evening stagnation or inversion conditions where it builds up the highest.

The other phenomenon that we saw, that in the concern for energy conservation people bought wood burning stoves or kerosene burners or whatever, they also sealed up their houses. The make-up air for the combustion of those fuels indoors was coming from somewhere, and in some cases we have seen houses where the air comes back down the chimney flue. It comes down the hot water heater or down the furnace flue and pulls those emissions back into the house.

And we—and this has happened in numerous cases and I think it is a serious, sort of accidental problem that can arise that the public isn't aware of. And it is due to weatherization and it is due to these other combustion sources indoors.

Mr. **Fuqua**. I feel a little healthier because I grew up in a house with a wood burning stove—stoves, but it was not airtight.

How far along are we in understanding the concentration rates and emission rates for ventilation and human activity? Are we getting a better understanding of that?

Dr. **Moschandreas**. Are you talking to me?

Mr. **Fuqua**. Any of you, but——

Dr. **Moschandreas**. I have been working on this subject the last 2 years and about 3 weeks ago I had the surprise of my life. I thought that all of my data base was incorrect. I found something that—all along we assumed that the emission rates are constant in time, so we gave one number which has been used extensively for estimating exposures in the indoor environments.

I found out that the emission rate is a function of time and it decreases as the time goes along. I spoke earlier today with Dr. Woods. He agrees with me. Lawrence Berkeley Laboratories—all independently we came to the same conclusion.

The point is that previous estimations of exposures were less than sound and we have to—when we use models, we have to take that under consideration. It will make considerable difference.

I am convinced that we are doing the right thing. However I believe that we need to establish a protocol whereby when I do the experiment I do the same thing that somebody else does, so when we compare the values we do not compare errors in the experimental design. Rather, we study the real emission rate.

We are in the right way, but we are not there yet.

Mr. **Fuqua**. Dr. Preuss.

Dr. **Preuss**. If I may interject. By way of an example, when we did our work on the kerosene heaters, we did both laboratory testing of maybe a dozen or two dozen heaters and we looked at the pollution situation in perhaps 175 to 200 homes with kerosene heaters and without. I would say in that study we more than doubled what had been done previously in this area. So that there has been some work done, but it has been extremely limited.

When we went to take a look at the patterns of use of kerosene heaters, we did not know them. We did not know whether people used them for 2 hours a day or 22 hours a day. When we went to take a look at the typical air exchange rates in houses, we had great difficulty in finding that.

So that in answer to your question, I would say that we have smatterings of knowledge across the board. In some areas, such as building construction, we may know a little bit more. In most areas we know very little, and this is why I think all of the speakers on this panel have indicated to you a strong need for research that will define these exposures and define the other parameters that go into defining what people are actually exposed to.

Mr. **Fuqua**. You—you mentioned in your statement about nitrous oxides. How serious are the consequences of an exposure and how much exposure do you need for—for that to be a problem and what effect does it have on elderly and people with pulmonary disease and maybe even, for that matter, children, and pregnancies?

Dr. **Preuss**. I probably am unable to answer any of those definitively or even approach them fairly closely. But one of the things that we——

Mr. **Fuqua**. Is the answer we really don't know?

Dr. **Preuss**. Well, there's—the answer is that we know a part of it and there is a—it is fairly controversial. For example, again, on this kerosene heater issue, the outdoor ambient standard for NO2 is 0.05 parts per million. The industry came in and had discussions with us and said that they felt that the levels at which one should be concerned should be 10 times that, 0.5. Our staff concluded that the level of concern was, by coincidence, halfway between, 0.25 parts per million and I—and in the chart that Dr. Moschandreas mentioned from the World Health Organization, that is, coincidentally, where they came out also.

But there is a great deal of discussion and controversy about this. There have been studies—and Dr. Spengler has been the scientist involved in some of these—that have looked at the health of people exposed to nitrogen oxides and other contaminants in the home, but unfortunately not all of the studies have come out in the same direction. So at this point I would say there is not unanimity about that.

Mr. **Fuqua**. How about with someone with pulmonary illness?

Dr. **Preuss**. I think there is much greater unanimity about the fact that people with pulmonary dysfunction are much more sensitive——

Mr. **Fuqua**. Any type of foreign substances aggravating——

Dr. **Preuss**. Well, particularly these kinds of materials which act as irritants to the lung, yes.

Mr. **Fuqua**. Dr. Woods.

Dr. **Woods**. May I add a comment to that? The—one of the concerns that I have in this regard is not only the concentration but the time of exposure and when that exposure occurs. One of the tests that we have recently conducted—and this was on NO_x—we were looking at the dispersion of the contaminant throughout the occupied space of the house, throughout the different rooms of a house. We looked at a bedroom door being closed, with the heater being in the living room area.

What we found is that the concentration many hours after the heater had been turned off was higher in the bedroom than it was in the living room, where the heater had been started.

So, I think that we need to know a lot about the occupancy patterns within a household, as well as where the source of contamination might be generated. So that just looking at the concentration I believe is not a sufficient criterion to really be able to assess what the exposure might be to that occupant.

Dr. **Preuss**. If I might add just a note again, we find, of course, that when one uses one of these sources, the pollutants begin to rise and then taper off and then as the appliance is shut off they begin to decrease again. So that equally of concern or perhaps of more concern is what is the effect of the very highest peak level and how long does that peak have to exist in order to exert an effect. And that is not known, either.

Mr. **Fuqua**. Thank you.

Mr. Scheuer.

Mr. **Scheuer**. No questions, Mr. Chairman.

Mr. **Fuqua**. Mr. Carney.

Mr. **Carney**. Thank you, Mr. Chairman.

Dr. Woods, I am going to ask you a hypothetical question. I am to build a three-bedroom home and I can give you $50,000 to do the HVAC work on it. Can you design a system that would eliminate most of the types of pollutants that we have discussed today and eliminate the problems associated with those pollutants?

Dr. **Woods**. Potentially yes, and I will qualify it in this regard, that knowing some information about the quality of the outdoor air, some information about the quality of the building materials and the sources of contaminants that may come from those building materials, we can probably design a system that would provide an acceptable environment indoors.

We know much less about the processes that would occur within that environment. Now, if we can assume that the processes or the activities of the occupants within that environment were known then, yes, the system could be designed. The technology is there.

The concern is that if you have all of the—let's say it is a single-family but all smokers in that family, then the concentrations are going to be considerably different than if you have a nonsmoking family. You can't assume that the system for the nonsmoking family would be acceptable in the condition for the smoking family. So there has to be some allowance made for difference in occupancy patterns.

Mr. **Carney**. I can appreciate that, but what I am saying is given the parameters of everyday type of living, the social background that we have established and you are in an area, you are in a community in the Northeast, you know what the outside ambience could be like and how they could change, and you know that the guy is not spraying airplane parts in his basement, you could then build some type of system to eliminate the types of problems we are talking about.

Dr. **Woods**. Yes. The way this is done currently is that consensus standards are promulgated. And those consensus standards give you an indirect method of control. There is so much ventilation that is specified to be brought into a given occupied space.

By consensus of people that are working in the profession from around the world, that amount of air is considered to be appropriate to give acceptable environment. In most cases that is successful.

Mr. **Carney**. But you can—I think of people living on submarines for 80 days or 90 days on the bottom of the ocean and we had the technology to maintain air quality there that I think to my knowledge is acceptable. In fact, I understand it is very, very clean.

Dr. **Woods**. That is correct.

Mr. **Carney**. I understand a submarine costs $2 billion and probably the air quality control part of it is a good cost involved in that submarine. But what I am trying to is we are faced with what I think to be two problems. One is really not a clear understanding as to the measurements of the pollutants.

Two, I think we have a public that quite frankly doesn't care. They would just rather put their head in the sand. You go to a cocktail party and you talk to your neighbors. You know how the Americans are. They are always trying to beat the system, you might want to say. And the question is, is how much you've decreased your electric bill or your fuel bill this year and the methods that they used to do it.

And I know—I can think of my own community, several engineers that are bright people that are using these kerosene burners and wood burners. You can't even breathe outside my community, and we have a breezy—I am being serious. We have a flow of fresh air continually.

I live on Long Island. There is always a good breeze, it is flat, no valleys, no nothing, but yet in the dead of the winter in the past 5 years you can tell the quality of the air has changed. I mean, it used to be fun. You know, it smelled nice. You thought you were in Maine. But then you start to realize that as more and more of them went on there was going to be a problem with it.

But they are not concerned with that. They are concerned with being able to pay their fuel bill at the end of the year, and many houses are already built with wood burning stoves or coal burning stoves or whatever, oil burning equipment, that we are not going to be able to retrofit. Many houses are built with insulation of asbestos and other chemicals that are causing us the problems.

I am just wondering, can we find a way to say well, there is really—the bigger problem of clearing up the inside and outside air quality is probably a tougher one to approach than building a machine that will do it withinside the house. And since we spend so many hours withinside the house—within the house, we might be better off going after designing that mousetrap.

Dr. WOODS. I think there is a couple of problems that you are identifying. One is what we mean by acceptable environment. Are we considering health hazards or are we considering comfort conditions? Do you want an odor free environment? Do you want to be free of risk? Is there a relationship between the two?

Much of the data that I have looked at, some that I have collected, some that others have collected, indicate that the ratio of concentrations indoors to outdoors typically will be three or four, that the concentration of most contaminants that we think of will be higher indoors than it will be outdoors.

Smoking, for instance, if you look at the total suspended particulates, you can see concentrations that will range up to 200 to 2,000 times what the ambient outdoor concentration might be under various conditions.

Mr. CARNEY. Well, you have a filtration system today that someone could buy to take care of the smoking problem?

Dr. WOODS. Sure, sure. The technology is there. The problem is the way it is used.

Mr. CARNEY. All right. Doctor, please.

Dr. MOSCHANDREAS. Could I——

Mr. CARNEY. Please.

Dr. MOSCHANDREAS. We are currently studying exactly the filtration system. There are many industrial claims of little gadgets—I don't even know how much they cost—which claim that you put it in the room and it will clean the air. We are currently studying the efficiency of those devices.

I think, to add to what Dr. Woods said, we have not really paid as much attention to cleaning the air as we should. I believe that if we focus on the problem, we will be able to come up with devices that will not eliminate, to use your word, we will not eliminate the indoor pollutants. However, we may be able to reduce it substantially.

Another point that I would like to make is that I receive in Chicago, I would guess, at least two or three calls every week from people who read newspapers and ask me, "What should I do with my source—this type of source and that type of source?" Or "Would you come and find out what the indoor air quality is in my house?" The problem is that they want all those things done free, and the answer more often than not is no.

However, there is an increasing awareness of the public of the potential problem, and I believe it is up to policymakers to make the public aware that there is a potential problem and would like to do something about it.

Mr. CARNEY. That was my next question to the entire panel, and that is I think—and I could be wrong. I make some assumptions on my own. But one of the problems that you are faced with is that, one, public awareness is very low and public concern is even lower. Even if they are aware of it, they just put it off. It might be because the public now can't put sugar in their coffee, they can't breathe air, they can't drive an automobile. Everything we do is either fattening, immoral, or is going to give you cancer.

I wonder if you are not faced with a problem which is indeed a big problem but yet you have the public who is just saying:

> Forget it. I have lived in a house with an oil burner in it or with a wood burner for so many years. I don't believe what these people are telling us, what the scientific community is telling us.

Dr. SPENGLER. I don't entirely agree with your assessment that there isn't a general concern out there. In February, Reader's Digest wrote an article on indoor air pollution, and one can now project 18 megapeople know about the problem. I will forget the other remark.

The other point is I think industry is going to learn about this issue and has already. A number of the paper and pulp industries are obviously concerned, the building industry is concerned, the auto industry and the utility industries that are strapped with very expensive outdoor controls are going to bring these issues to you to say, you know, what is going on here. Are we really achieving public health benefits from the multibillion-dollar control efforts.

Most of those standards are all predicated on outdoor air quality levels and achieving them by stationary monitors out in the middle of the community, and there are, as pointed out there, the bulk of the exposure for some pollutants, not all, but the bulk of them are occurring indoors. And that's where the elderly are, that's where the children are, in a disproportionate amount of time to compare to the rest of it. So I think in general there is going to be a response across society to these issues.

Mr. **Carney**. Do you think that will change the public—well, that's—that's—I am glad to hear that because, you know, I can appreciate the frustration you are faced with in dealing with the unknown scientifically and the fact that then when you do find something it is probably rather difficult to get that out into the public view.

Dr. **Spengler**. There is another point. We are talking about 80 million residential units in the United States, 20 million other types of indoor environment, and we have probably measured in 3,000 of them. And these are sporadic measurements. They are not long term, they don't really characterize what is going on, but they have provided enough evidence on radon and biologic materials, on chlordane, on formaldehyde to say yes, people are seeing levels that are high enough to give them irritation, high enough to give them health effects, but yet we don't know the total population at risk at this point.

Mr. **Carney**. Dr. Woods.

Dr. **Woods**. Yes. I would like to just add one more point I guess on the public awareness. I think a point that really needs to be expressed to the general public is the economic advantage of proper environmental control; that if they controlled the systems that are installed in their homes or in their buildings correctly, usually according to the design that was originally prepared for that facility, that the system will operate more efficiently than in some of the modifications that they may have made because they think that the system will operate better their own way.

As we look at the type of environmental control and we begin to better define what is happening in those occupied spaces, we can find better ways to control that environment and from an economic standpoint the energy costs can go down. So the operating costs are going to go down and the first costs, because the equipment is going to be smaller, will usually go down as well. So there is a very strong economic incentive, I think, to look to improved indoor environmental quality.

Mr. **Carney**. Dr. Preuss, we have what I think to be a fragmated—fragmented approach to this now in Government since we have so many agencies trying to deal with indoor air quality. Would you suggest that we try to create an umbrella agency in maybe Energy or any particular agency to try to address this, focus our resources better, get more value out of the tax dollar that we are spending on this problem?

Dr. **Preuss**. I think the suggestion that has been made by some members of this committee to establish a Federal coordinating committee chaired by the Environmental Protection Agency and cochaired by us and by the Department of Energy, with membership of other agencies, is a very good idea.

In practice, we have been meeting for several years already on an informal basis to discuss these kinds of issues and to coordinate what it is that we are doing. We have been very aware of exactly the concern that you raise, and as a result, for example, when we went to look at volatile organics inside residences and EPA was looking at volatile organics as well, had an interest, we developed a joint plan, so that they would do certain things and we would do certain things, so as neither to duplicate nor to miss something that was important.

I think that has gone on in an admirable fashion on an ad hoc basis, and I would certainly support formalizing that and having this done on a more coordinated interagency basis, yes.

Mr. **Carney**. Thank you, and I will yield to the Chair.

Mr. **Fuqua**. Thank you.

Mrs. Schneider.

Mrs. **Schneider**. Thank you very much, Mr. Chairman.

Dr. Spengler, I wonder if you could please pick up where Dr. Freuss' comment left off, and that is in reference to the multiagency task force that members of this committee have recommended. Do you think that this is a good approach?

Dr. **Spengler**. Yes, I do. I think—I would make some arguments to say why I personally feel that EPA should take the lead in this thing. I think they have a clear mandate for public health issues related to environmental toxins of a variety of natures: Pesticide controls, toxic hazardous wastes, radiation through radon controls, in general outdoor air pollutants, many of which appear indoors.

And further, they have a regulatory structure that permits—that is already exercising a variety of kinds of responses, from standard setting and controls to permitting and processed right from source control, right from manufacturer on down. So I think they have a variety of experiences.

In addition, they have carried out large monitoring programs and have built up a very good quality assurance lab. So that is my personal feeling why I felt that they were best suited to take the lead, but it is clear that other agencies have special interests here—you know, DOE, HUD, Consumer Products Safety—that really need to be brought into this. And it is—where they—for instance, where DOE could be examining building products and energy conservation aspects and fuel efficiencies, all related to indoor environment—environmental quality. I think that's an appropriate role for them to be playing.

Mrs. **Schneider**. Good. Well, I thank you for so strongly supporting the framework that I had established in my amendment, which I received the support of members of this committee and the chairman. We also do call for the inclusion of HHS because of their experience in studying chronic illnesses.

Dr. **Spengler**. Very clearly, I think through the National Institutes of Health, obviously they should not be ignored.

Mrs. **Schneider**. I would also like to ask you if you perceive any institutional problems that might exist in establishing an indoor air research program?

Dr. **Spengler**. I don't think I am best qualified to respond to that. You can always envision lots of entrenchment in certain areas, but I think one would reflect on what I see as some good leads and good starts in the cooperation among agencies as it has taken place in the last couple of years. They have cosponsored national meetings; international meetings, in fact. They have shared in a lot of their research efforts.

And this is going to cost a lot of money to conduct a very systematic approach, just studying the multifaceted problems that we have with indoor environments. And so it is going to take the resources, I think, of several agencies to go to work on this thing. And I can't respond to the institutional barriers.

Mrs. **Schneider**. How serious of a health problem do you——

The **Reporter**. Excuse me, Mrs. Schneider. Could you please move to another microphone?

Mrs. **Schneider**. Use another microphone?

The **Reporter**. Please. That one is not working.

Mrs. **Schneider**. Are you leaving? You don't have to leave. I don't mean to run you out of town here.

Insofar as the health effects are concerned, Dr. Spengler, do you have any particular insights to share with us as to how serious a problem you believe this to be and how can we best interpret it for our constituents who, as Mr. Carney was saying earlier, might attempt to fluff off this issue?

Dr. **Spengler**. I think part of the problem is, as you know, like I said before, the individual doesn't obviously have clear signals that the levels are high in the environments that they are in.

For instance, if we had high CO in this room right now, we would never know it, until we all fell asleep or had headaches. And the same thing for radon. You don't have any sensory perception. Nitrogen dixoide the same way. So that—and many of the pesticides that are slowly evolving from applications in restaurants, in houses and buildings, and we are not even aware of the multitude of exposures that we currently have. So, the fact that the public doesn't have a good sense and can't respond right now is not surprising. They don't have clear signals.

As to the seriousness of the health effects, I think there are many ways of cutting—to cut this. Clearly you might look at it in terms of the overall impact, those pollutants that are known carcinogens. You might say, well, that is the most serious, or those that are related—cardiovascular disease. They are the most serious.

And in that category would be radon, would be carbon monoxide. In fact, we have many deaths in the United States from carbon monoxide poisoning inside our homes. Mostly they are the accidental variety, but—and you could go down the ranking of health effects to morbid conditions that lead to slight increases in respiratory ailments which again we are not aware of, but the evidence is becoming more clear that passive exposure to cigarette smoke is giving children living with parental—parents that smoke a higher rate of respiratory diseases, 15 to 30 percent for some types of diseases.

Now, that is very difficult to assess. It is sort of in the general background of illnesses. And it takes, you know, a multimillion-dollar effort to really sort out these effects from other possible environmental or biological impacts.

So, you have a whole set of categories that are in the respiratory and other illness and then you have another set of health effects problems that are irritant problems, such as formaldehyde. And maybe it is just the respiratory irritant, that when you remove yourself from the source, then you—then, you know, the symptoms go away.

But yet where that occurs in your home or occurs in the workplace, it is not to be dismissed as a not as significant health effects because it is impairing your enjoyment of those environments. And so it can develop other sorts of stress or life stress.

Well, another way of framing the problem would be to look at the potential for population exposures. And we know that nitrogen dioxides, say, or other contaminants from gas cooking, although we don't have good information on the direct health effects of these things, animal studies, clinical studies tell us we should be concerned about it. The population exposure is very large. Half the homes in America.

If you look at cigarette smoking again, 33 percent of the population smokes, but when you look at either/or of a husband-wife smoking and sibling smoking, it's probably 50 to 60 percent of the homes have smokers. So the numbers are really large.

Mrs. **Schneider**. It is devastating.

Dr. **Spengler**. Radon, we have no idea on how extensive the radon exposure is, but there you have the strongest evidence for health effects.

So I would say at this point it is extremely difficult to give precise answers on the magnitude of the problem, and that is just the basis for the recommendations that we are making to do this national survey.

Mrs. **Schneider**. I thank you very much.

Dr. Moschandreas, I wonder if you could please elaborate a little bit. I understand that you do work under contract for the Gas Research Institute. Is that correct?

Dr. **Moschandreas**. That is correct.

Mrs. **Schneider**. They spend somewhere between $2 and $4 million a year on indoor air research? Is that about on target?

Dr. **Moschandreas**. I wouldn't know. They do not spend that much for my research. [Laughter.]

Mrs. **Schneider**. Well, now, if there is new information, you are going to have to check that out with them, huh?

I wonder, have you published all of the results of the research conducted for GRI?

Dr. **Moschandreas**. I have not published it yet because the research is ongoing right now. I assume that we will publish it when we finish, but if you wish to have data this moment, it will have to come from the Gas Research Institute.

Mrs. **Schneider**. I see. Have they ever not published any of your findings?

Dr. **Moschandreas**. No.

Mrs. **Schneider**. They usually——

Dr. **Moschandreas**. I have no difficulty—as a matter of fact, I understand—and the Gas Research Institute representative isn't here, so he can't answer it. They encourage publications.

Mrs. **Schneider**. Good. Good, good.

The only other question I have is less of a question; more of a request. If there is anyone at the witness table or in the audience that is capable of setting up a monitoring system or is interested in setting up a monitoring system, I have a very unique problem at hand that a constituent of mine is experiencing that seems to be getting no assistance from the State, no response from the Environmental Protection Agency, and we are at loose ends as to how to address this problem, so if someone would like to see me afterward about that, I certainly would appreciate it.

Thank you, Mr. Chairman.

Dr. **Spengler**. Could I just point out——

Mrs. **Schneider**. Yes.

Dr. **Spengler** [continuing]. I think you have hit on one of the institutional barriers, and a lot of the information, the concerns from the public is coming in at State levels, State public health agencies, State air pollution agencies. They are not set up—they don't have the backup nor the experiences nor the instruments to respond to this problem. And nothing is coming down from the top to give them that strong support, either.

Mrs. **Schneider**. Good. Thank you very much.

Thank you, Mr. Chairman.

Mr. **Fuqua**. Thank you very much.

We want to thank our panel for being here this morning. We deeply appreciate your contributions. Thank you very much.

Our next panel on energy conservation and indoor air quality research will be Dr. Anthony Nero from the Lawrence Berkeley Laboratory; Dr. Ward Alter, president of Terradex Corp. from California; and Dr. C. T. Hess, professor of physics at the University of Maine.

Dr. Nero, we would be pleased to hear from you. And as I had mentioned to the earlier panel, if you wish to summarize your statements and submit the prepared text, we will make that part of the record, if you so choose, and all of that.

[The biographical sketches of Dr. Nero and Dr. Alter follow:]

Anthony V. Nero, Jr. - Biographical Sketch

Dr. Nero serves as co-leader (with Dr. David T. Grimsrud) of the Building Ventilation and Indoor Air Quality group at the Lawrence Berkeley Laboratory (LBL). He received his Ph.D. in physics at Stanford in 1971, after which he continued teaching and basic research in experimental nuclear physics as a research fellow at California Institute of Technology and assitant professor of physics at Princeton. Since before his arrival at LBL in 1975, he has performed research on the environmental effects of energy, initially emphasizing nuclear energy and health risk assessment and concentrating in recent years on indoor pollutant behavior and radon characterization. He is author or editor of 4 books or volumes on energy and environmental topics, and author of approximately 65 journal articles, book chapters, research reports, and conference presentations. He is chairman of the American Physical Society's Subcommittee on Studies (of the Panel on Public Affairs) and serves on the Advisory Committee for the Third International Conference on Indoor Air Quality and Climate (Stockholm, 1984) as well as the National Council on Radiation Protection and Measurements Scientific Committee on Radon Measurements. He is a member of the American Physical Society, the American Association for the Advancement of Science, the Health Physics Society, and the Air Pollution Control Association.

BIOGRAPHY

Dr. H. Ward Alter

Dr. Alter is President, Terradex Corporation, Walnut Creek, California. He received a BA in 1943 and a Ph.D. in Physical Chemistry in 1948 from the University of California at Berkeley. From 1948 to 1974 he held several scientific and managerial positions in the General Electric Company. Dr. Alter formed Terradex Corporation in 1974 to apply Track Etch® technology to the measurement of radon gas in the environment. He is a Fellow, American Nuclear Society and a member of Phi Beta Kappa, the American Chemical Society, and the Geochemical Society.

STATEMENTS OF ANTHONY NERO, GROUP LEADER, INDOOR AIR QUALITY, LAWRENCE BERKELEY LABORATORY; H. WARD ALTER, PRESIDENT, TERRADEX CORP.; AND CHARLES T. HESS, PROFESSOR OF PHYSICS, UNIVERSITY OF MAINE

Dr. NERO. Yes, thank you very much. That is what I would prefer, Mr. Chairman.

Mr. FUQUA. Thank you. We are pleased to have you.

Dr. NERO. Thank you.

I am Tony Nero from the indoor air quality group at Lawrence Berkeley Laboratory, and we are pleased to be invited to help review with you the question of indoor air quality. And I am going to review work that pertains not only to radon but also to other work at Lawrence Berkeley Laboratory.

It is now known that the indoor concentrations of several important classes of pollutants vary very widely within the U.S. building stock, ranging from concentrations of very low levels that have little or no health concern to concentrations a thousand times higher that are of substantial health concern, and that those exposures sum to a potential for thousands of deaths per year among the U.S. population and a much greater incidence of acute and chronic disease.

The wide variability in concentrations arises largely from differences in source—sources that are present and in emission rates, and also because of differences in ventilation rates and other building-related factors.

The large health implications dictate the need for substantial work on characterizing pollutant behavior—can you now hear me?—monitoring levels indoors, examining health effects, and formulating control strategies.

I am going to speak in particular about the problem of the detailed characterization of pollutant behavior; that is, investigating the dependence of indoor pollutant concentrations on sources, ventilation rates and other building-related factors, these dependencies being fundamental to an understanding of the relationship between energy conservation and indoor air quality.

Lawrence Berkeley Laboratory's work has focused on such studies beginning about a decade ago with studies on the emissions from gas cooking appliances and expanding to a rather full range of work on the dependence of pollutant concentrations on building-related factors. This has included field studies ranging from the use of large mobile laboratories, for intensive investigations in small numbers of houses, to the use of very simple monitoring devices in rather larger numbers of houses.

But the main part of our work has been the detailed characterization of pollutant behavior in environmental chambers, in test houses, and in other laboratory facilities.

Such work is fundamental to the design and interpretation of large-scale monitoring studies. It's necessary for the assessment of the health effects of these pollutants, and it is absolutely necessary for understanding the effect—the relationship between energy conservation and indoor air quality and to the evaluation of different kinds of control techniques that might be used.

I will mention some of the specific areas in which LBL has conducted work, and it really spans the range of the different kinds of studies that have been mentioned here before.

Our work on combustion products, as examined emissions from gas stoves, from kerosene heaters, from unvented gas-fired space heaters, and from wood stoves, examining emission rates in indoor concentrations, as well as how pollutants are transported indoors.

Our work on radon has indicated that the very wide variability in concentrations observed indoors arises largely from differences in the rate at which radon enters houses, and this in turn depends both on the variability in the amount of radon coming from the various source materials, and on the effectiveness of the house under structure as a barrier to radon entry.

We've studied particulate behavior in the context of both combustion product emissions and in the context of radon daughter behavior, radon progeny behavior, and consider particulate composition and interactions to be examples of areas that require substantial work characterizing the behavior of indoor pollutants.

Our studies of formaldehyde have shown a clear dependence of concentrations on the products used in buildings and on the environmental conditions in those buildings, and our work on volatile organics has focused on the same questions.

Our work on development of passive samplers has substantially increased the capability of the research community to monitor indoor concentrations of a variety of pollutants in large-scale survey efforts, and that work on samplers has included samplers on NO_2 formaldehyde, carbon monoxide and water vapor.

Our work on control techniques has included study of the thermal environmental performance of mechanical ventilation systems that employ air-to-air heat exchangers, as well as work on other air cleaning techniques and on the question of the distribution of air within a building.

Finally, our current understanding of pollutant concentrations and their distribution indicates significant health concerns for even average levels of some pollutants found indoors and very substantial health concerns for the higher levels of pollutants in each class of interest.

Turning just for a moment to particulates, in many cases indoor concentrations of particulates, measured either as total amounts or as respirable amounts, are known to approach or exceed outdoor levels or the standards that apply outdoors. The strongest source of particulates indoors is ordinarily smoking but particulates arise from combustion appliances, from materials used in the house, and from outdoor air.

A point to be aware of, though, is that even when the total particulate concentration is not very large by outdoor standards, the particulates found indoors can be worrisome because they are typically in the respirable size range, they contain chemicals that are of special concern from a health point of view, and also they interact with gaseous species indoors, which can have a substantial effect on the indoor concentrations and on the health effects that arise from those pollutants.

Let me take radon progeny as an example. The radioactive decay products of radon, which are isotopes of polonium, lead and bismuth, can attach to particles in the air. And when you inhale, you can inhale those particles and they can lodge in the lung, causing an exposure, a radiation exposure to the surrounding tissue.

On the other hand, the radon progeny that don't attach to particles are also of concern and can, in fact, cause an even larger dose to the lung, so that you might think in the first place that by lowering particulate concentrations you lower the exposure to the lung, but in fact exactly the opposite may happen.

Now you may be a little puzzled by what I have just said, but the fact is so is the scientific community, and this is just an example of the kind of question that has to be investigated much more thoroughly by basic characterization efforts.

A general conclusion to be reached from such work as ours is the need to consider explicitly the dependence of indoor concentrations on various factors. Now one of these, ventilation rate, provides the apparent connection between energy conservation measures and indoor air quality.

Among other objectives, energy conservation measures seek to reduce the approximately $50 billion a year that goes out the window because of heating and cooling energy costs associated with ventilation.

A single family house in a mid-Atlantic State can expect to spend hundreds of dollars heating and cooling the about three-quarters of an air change per hour that is a typical ventilation rate in a home.

That loss of energy resources and wealth is important to the individual and it is important to the Nation, and it can be reduced substantially if ventilation rates can be reduced, which can happen if either sources are low indoors or if ventilation reduction is accompanied by air quality control measures.

But it is not a simple matter because three-quarters of an air change per hour itself is not enough to assure indoor air quality if, in fact, the sources that you have indoors are extremely large. And we know that the source terms—that is, the emission rates—vary substantially within the housing stock.

So it is clear there is a substantial need for research characterizing what affects indoor pollutant concentrations. The need is apparent for a vigorous, national effort in this area. With each pollutant class there are specific, continuing research needs on how the pollutant concentrations depend on sources, on how emission rates vary with environmental factors, and how the pollutant concentrations are affected by ventilation rate and other building-related factors.

Such basic characterization efforts are closely tied to other efforts to monitor exposures in large numbers of houses and to assess the health effects of those exposures. And this requires very strong cooperative efforts within the scientific community, as will become apparent if a national survey of indoor air quality is mounted.

And as a final note, the research that is necessary on pollutant behavior, on public exposures, and on the anticipate health effects can really only be performed effectively as part of a national program. This cannot be expected to be accomplished in a happenstance manner. It requires the vigorous, well-coordinated efforts of the several Federal agencies, including the ones that have responsibilities for building science and energy conservation, for appliances and products, for environmental protection, and for the public health. Only then will indoor pollutants be understood well enough to serve as a basis for action.

Thank you very much, and I will await questions.

[The prepared statement of Dr. Nero follows:]

THE DEPENDENCE OF INDOOR POLLUTANT CONCENTRATIONS ON SOURCES, VENTILATION RATES, AND OTHER REMOVAL FACTORS

Statement before a joint hearing of the
Energy Development and Applications
and Natural Resources, Agriculture
Research and Environment Subcommittees of the
House Committee on Science and Technology
on
INDOOR AIR QUALITY RESEARCH: CURRENT STATUS AND FUTURE NEEDS

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Introduction

We appreciate the invitation to review with you the question of indoor air quality: what has been done to this date, what the current state of understanding is, and what needs to be done in the foreseeable future, all to elucidate the degree of human exposures to indoor airborne pollutants, the factors affecting those exposures, their effects on human health, and what may be done to assure adequate indoor air quality. Our current understanding is now sufficient to state that indoor concentrations of important airborne pollutants often exceed outdoor levels, an ironic state of affairs considering the substantial efforts that have been devoted to characterizing and controlling outdoor pollutant levels, and the fact that the population actually spends most of its time indoors. For pollutants where such comparisons are possible, indoor concentrations often exceed outdoor air quality standards, sometimes by large factors, and -- for some pollutants -- indoor concentrations even appear to exceed occupational standards in a significant portion of the building stock. Hence the interest in devoting substantial efforts to this problem, including the aspect that I will emphasize, i.e., the characterization of indoor pollutant behavior.

In addressing this question I will include the behavior of several classes of chemical and physical pollutants: emissions from combustion appliances; radon and its progeny; and formaldehyde and other organics. I will not review various living organisms present in indoor air, or even special chemical and physical materials that are sometimes present. As you will see, this question of the dependence of indoor pollutant concentrations on sources, ventilation rates, and other removal mechanisms, for which I use the expression "indoor pollutant behavior," is closely tied to understanding how energy conservation is related to indoor air quality.

In what follows, I will

1) indicate briefly the role of research on indoor pollutant behavior in the context of overall research on indoor air quality;

2) summarize key aspects of the work of our group at Lawrence Berkeley Laboratory (LBL), on the most important research needs in these areas of indoor air quality, emphasizing questions of pollutant behavior and pointing out the most important research needs in these areas;

3) review specifically the current state of knowledge of particulates, radon progeny, and their control; and finally

4) summarize general research needs on the behavior of indoor pollutants, indicating how this research ought to fit into the overall work to be performed on indoor air quality.

Characterization of Pollutant Behavior: A Principal Element in Indoor Air Quality Research

Broadly speaking, the ultimate objectives of indoor air quality research are to determine human exposures by measurements of pollutant concentrations ("monitoring"), to ascertain the effects of these exposures on the health of the population ("health studies"), and to formulate strategies to limit exposures and associated health effects ("control strategies"). It is easy to leave out a fourth principal topic that is investigated to a greater extent in the laboratory and which to a substantial degree underlies these three more apparent research areas, i.e., pollutant characterization.

A satisfactory understanding of indoor air quality clearly requires study of how pollutants behave indoors: the sources of pollutants, the effect of changes in ventilation rate on concentrations, and the manner in which pollutants are transformed or removed by interactions with each other or with the building and its contents. Moreover, study of these questions is clearly required to achieve the main objectives of indoor air quality research: monitoring cannot be performed properly or interpreted adequately without laboratory studies of pollutant behavior and, conversely, the results of large-scale monitoring contribute directly to an understanding of the factors determining pollutant concentrations in the actual building stock; health studies require adequate characterization of the pollutant mixtures to which humans are exposed, which are sometimes even parameterized in terms of the factors, such as sources and ventilation rates, which affect these concentrations and control strategies can only be chosen with an understanding of the factors affecting pollutant concentrations and of the effectiveness of various techniques for reducing them.

The situation is entirely analogous to understanding important problems with the outdoor atmosphere, such as acid rain or CO_2. For such questions, outdoor monitoring is only one component in a research strategy that must also contain experimental and theoretical studies, often laboratory based, to elucidate the chemical and physical mechanisms at work and to provide a basis both for interpreting measurements performed in the atmosphere and for adopting control strategies. As you will see, much of the work of the group at LBL is directed to analogous characterization studies that are fundamental to an understanding of indoor air quality.

Such studies are, of course, at the heart of understanding the relationship between energy conservation and indoor air quality. It is the building shell, its contents, and local physical and environmental factors that determine pollutant concentrations indoors. In general, these are the same factors that affect energy consumption in homes and other buildings. Conversely, efforts to save energy can alter building-related factors, including not only ventilation rates, but also material and appliance source types and other factors affecting concentrations. Moreover, efforts to control indoor concentrations, whether increases due to energy-saving measures or concentrations that were excessive in any case, require attention to such building-related factors.

Indoor Air Quality Studies at the Lawrence Berkeley Laboratory

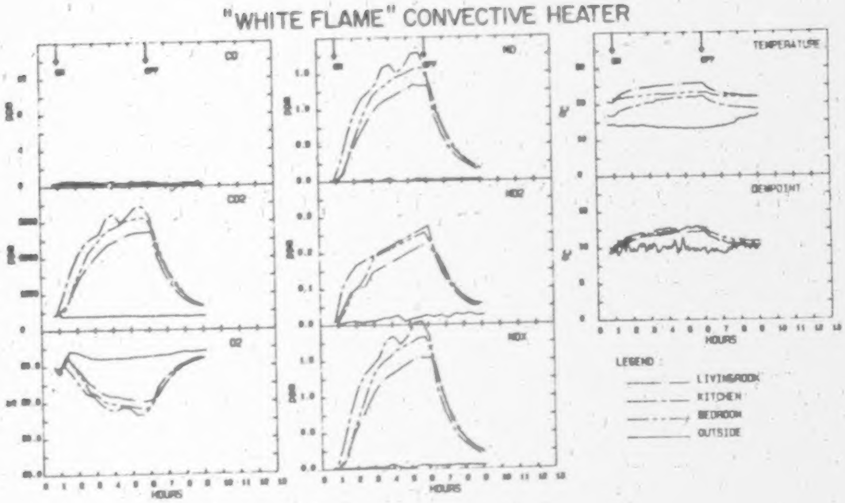
Work on indoor air quality at LBL began with a study of emissions from combustion appliances, following measurements in local homes that showed that concentrations of key combustion products were often much higher indoors than outdoors, although air quality standards presumed that outdoor levels were those of concern (Ref. 1). Beginning in 1976, the program expanded substantially, in order to ascertain the potential effects of energy conservation measures on indoor air quality and to understand how to avoid significant deterioration. This program has had diverse elements, many of which I will indicate briefly.

Before proceeding to the core of that work, most of which has been performed in the laboratory or in "research houses," I should mention that one of the major elements of this expanded program was a large mobile laboratory that traveled around the country to a variety of homes and other buildings, carrying with it instrumentation for monitoring a wide range of pollutants intensively over long periods of time (Ref. 2). The mobile lab effort gave a substantial amount of basic information on the occurrence of these pollutants indoors (e.g., Ref. 3). What it also indicated fairly clearly, consistent with our earlier work, was that the major question for indoor air quality was not the pollutants that entered from outdoor air, but rather those released directly into buildings from the materials or appliances that generated them. Although there are exceptions to this generalization, this meant that characterizing indoor air quality was principally a question of the study of indoor-generated pollutants. The major connection with outdoor air quality issues is that the vast attention paid to improving outdoor air quality and controlling emissions into the general environment, while important, has tended to ignore the fact that most human exposures to air pollution may occur to the general population in their homes and non-industrial work places, where levels often far exceed outdoor levels and where people spend most of their time.

Our research has therefore tended to emphasize characterization of the dependence of indoor concentrations on sources, ventilation rates, and other factors that cause pollutant transformations or removal indoors.

combustion products: Our group has characterized emissions rates from gas stoves, kerosene heaters, and unvented gas-fired space heaters in an environmental chamber, and has also studied these devices (and wood stoves) in test houses. The objective has been to determine, not only their effect on indoor concentrations, but also the manner in which emissions propagate through a structure under various ventilation conditions. The result of such work is the knowledge that some emissions, such as oxides of nitrogen and carbon, can reach very high levels indoors. Even so, it is clear that further work is required in characterizing emissions from combustion appliances, and in understanding their transport and transformation properties (e.g., NO/NO_2 conversion) in indoor atmospheres. These issues are important, not only for understanding potential exposures and control measures, but also for characterizing the performance of monitoring instrumentation and the effectiveness of potential measurement strategies. (See Figs. 1-2 and Refs. 4-8)

radon and its progeny: We have measured radon emission rates



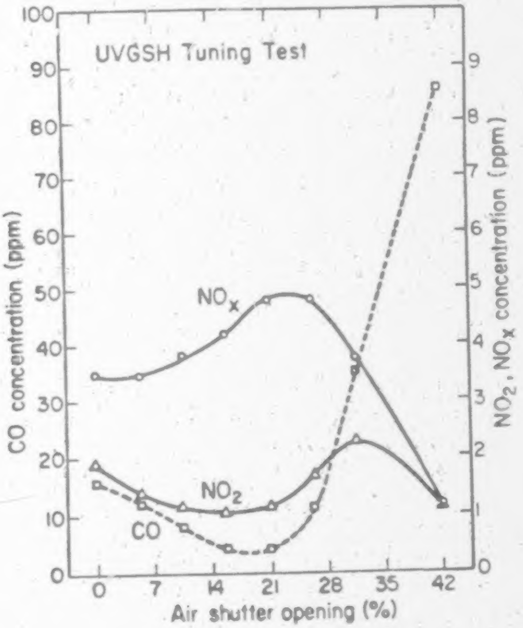
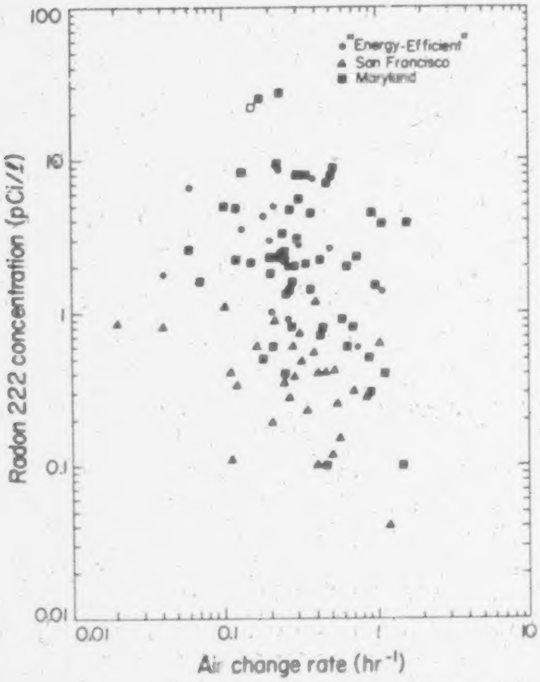


Figure 1 (top) Concentration profiles of emissions during operation of a portable kerosene-fired space heater. The heater was located in the living room of a 240 m^3 house with 0.55 air changes per hour.

Figure 2 (bottom) Peak pollutant concentrations as a function of air-shutter opening for an unvented gas-fired space heater. Measurements were made in a 27 m^3 chamber with 0.4 air changes per hour.



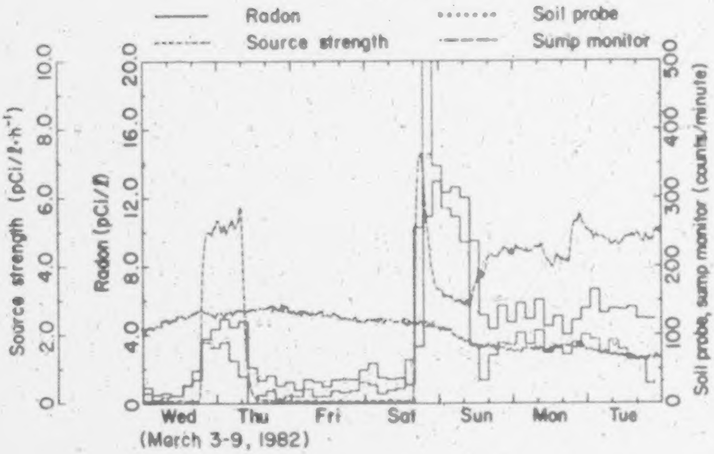


Figure 3 (top) Measured radon concentrations and ventilation rates in energy-efficient and conventional houses (about 100 houses total).
Figure 4 (bottom) Radon concentration, radon source strength (calculated from the radon concentration air-exchange rates), alpha radioactivity in soil gas and in air above a basement sump pump. Data are from a single-family house near Chicago.

Table 1

Indoor Formaldehyde Concentrations in a New Residential Building in Mission Viejo, CA

Condition	Formaldehyde (ppb)
Unoccupied, without furniture[a]	67 ± 9%
Unoccupied, with furniture[a]	186 ± 7%
Occupied, day[a]	218 ± 10%
Occupied, night[b]	117 ± 31%
Outdoor Air	<17

[a]Air exchange rate = 0.4 h^{-1}

[b]Windows open part of time; air exchange rate significantly greater than 0.4 h^{-1} and variable.

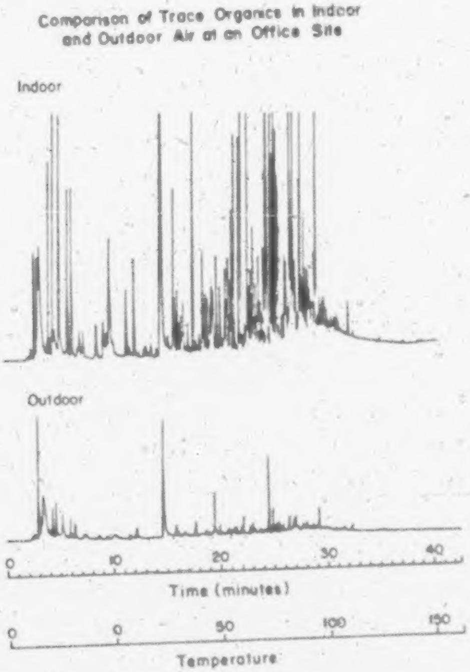
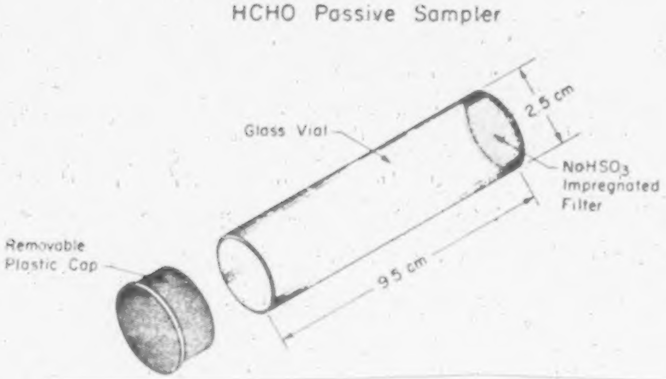

Comparison of Trace Organics in Indoor and Outdoor Air at an Office Site

Figure 5 Comparative gas chromatograms from inside and outside an office where complaints had been registered regarding indoor air quality. Equal size air volumes were sampled using the Tenax-GC polymer. Individual peaks correspond to different chemical species or groups.


HCHO Passive Sampler
Glass Vial
2.5 cm
NaHSO$_3$ Impregnated Filter
Removable Plastic Cap
9.5 cm

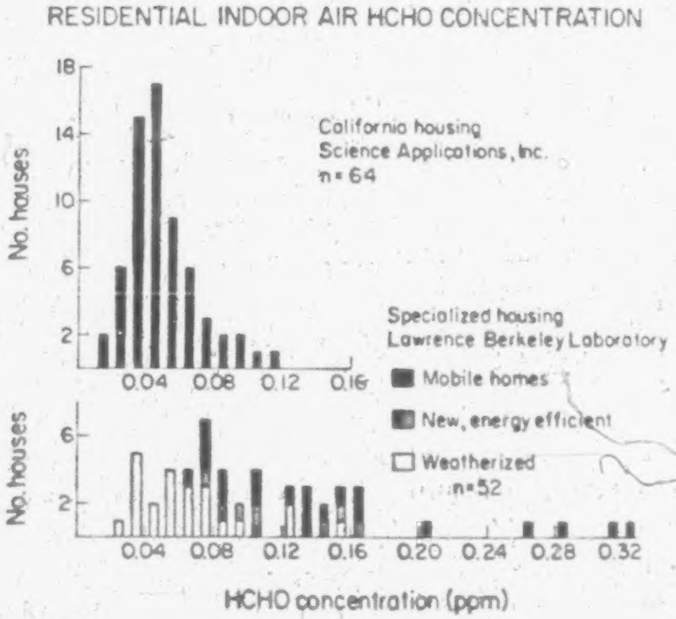


Figure 6 (top) Passive formaldehyde sampler designed at LBL. Formaldehyde diffuses into the glass tube after removal of the cap for a specified period of time. After recapping, the filter is analyzed for HCHO in the laboratory using the chromotropic acid method.

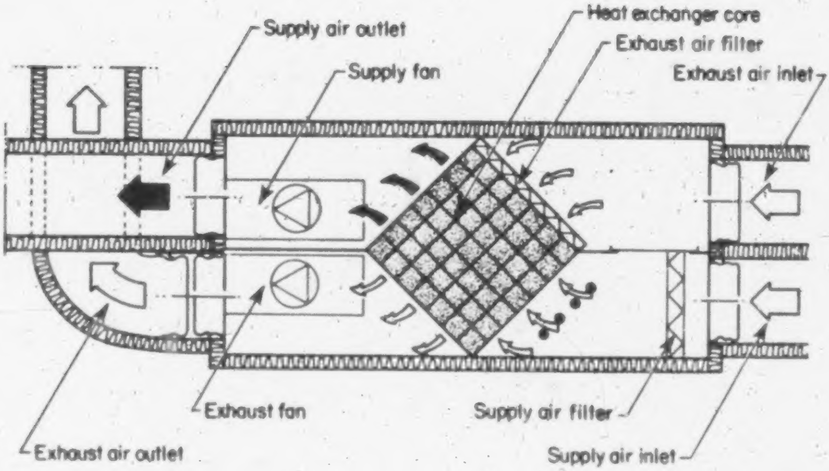
Figure 7 (bottom) Measurements of formaldehyde concentrations in conventional (top data set) and specialized (bottom data set) housing in California. These data were collected using the HCHO passive sampler.

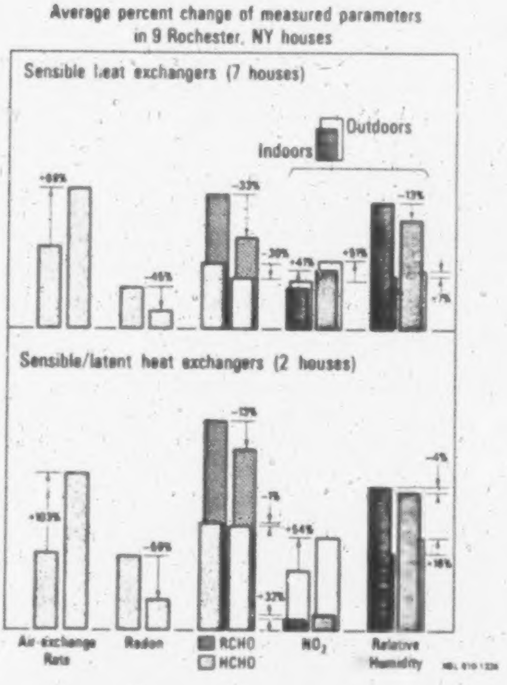
from concrete samples collected around the country, and have performed concentration measurements and ventilation rate measurements in several samples of housing. This work led us to the conclusion that the main source of indoor radon is usually the soil and rock underlying buildings, and that it is the variability in the entry rate from this source that causes most of the hundred- or thousand-fold differences in radon concentration seen from house to house. Thus ventilation rate is not ordinarily the main consideration for indoor radon. We and others in the community are now heavily engaged in studies to understand in more detail how radon enters houses and how radon progeny behave after they are created from the radioactive decay of radon in indoor air. As described below, the behavior of the progeny depends heavily on their interaction either with airborne particles (e.g. from combustion sources) or with the building structure and its ventilation systems. (see Figs. 3-4 and Refs. 9-15)

formaldehyde and other organics: Work on formaldehyde has demonstrated a clear dependence of the indoor concentration on a building's materials or contents; future work ought to include study of the dependence of formaldehyde emission rates on indoor conditions: temperature, humidity, and ventilation rate. Our work on organics, in addition to demonstrating directly the presence of a large array of compounds in commercial buildings at levels that far exceed concentrations outside the buildings, has focussed on characterization of the emission spectrum from various building materials and on the correspondence between this information and the substances actually found to be present in indoor air. Further work required is the determination of emission rates in an environmental chamber that can provide realistic conditions, the development of more effective (e.g., simpler) monitoring approaches, and the establishment of a data base for developing a correspondence between concentrations observed in buildings and health effects among the occupants. (See Tables 1, Fig. 5, and Refs. 16-19)

development and characterization of passive samplers: In support of our interest in elucidating the dependence of indoor concentrations on various factors, we have devoted significant effort to advancing the state of the art of passive samples, including testing of the performance of an NO_2 sampler that was previously available, development and testing of a formaldehyde sampler that is now widely used, and -- currently -- development of samplers for CO and water vapor. The facility we have established is unique in its capabilities for characterizing performance of such integrating passive devices. It can therefore lend direct support to formulation of large-scale monitoring efforts that use such samplers. It can also be used for developing novel applications of these devices to the measurement of air velocity and ventilation effectiveness, questions that are of substantial interest in characterizing the behavior of indoor air pollutants. (See Figs. 6-7 and Refs. 20-21)

control techniques: Our largest effort in this area to date has been the characterization of the thermal performance and environmental effectiveness of systems that provide ventilation, thereby removing pollutants, while incorporating air-to-air heat exchangers to recover heat that would ordinarily be lost with the ventilation air. Recent


Supply air outlet
Supply fan
Heat exchanger core
Exhaust air filter
Exhaust air inlet
Exhaust fan
Supply air filter
Exhaust air outlet
Supply air inlet



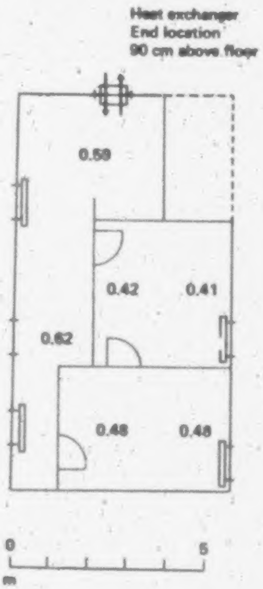

Heat exchanger
End location
90 cm above floor
0.59
0.42
0.41
0.62
0.48
0.48
0
5
m

Figure 8 (top) Schematic of a mechanical air-to-air heat exchanger.
Figure 9 (left) Percent change in environmental parameters before (left bar) and after (right bar) heat exchanger installation.
Figure 10 (right) Relative ventilation effectiveness at various locations within the test space.

work includes the study of the effectiveness of this approach in providing ventilation throughout the space in single-family dwellings, study of ventilation effectiveness for other types of systems, and experiments on the use of air washing to remove formaldehyde from indoor air. Substantial work remains to be done, not only on the topics just mentioned, but on other pollutant-specific control techniques, ranging from examining how different wall materials selectively remove chemically active airborne pollutants (such as NO_2 or radon progeny) to the effectiveness of various active air-cleaning and ventilation techniques. Examples are given below in the discussion of particulates. (See Figs. 8-10 and Refs. 22-26)

Some general conclusions can be derived from this broad range of work on indoor pollutants:

-- perhaps most significant from the point of view of energy conservation is that, although it is clear that a substantial reduction in ventilation rates (e.g., by the factor of 5 or so that is within technical reach) would have a strong adverse effect on indoor air quality -- at least in the absence of corresponding control measures -- the main cause of widely different indoor concentrations in the ordinary housing stock is the strength of pollutant sources rather than the variability in ventilation rates. This is not to say that ventilation rate is not important, but rather that assurance of good indoor air quality requires attention to both sources and ventilation rates, as well as other factors that affect indoor concentrations.

-- monitoring programs and exposure characterization have to take account of the various factors affecting indoor concentrations, and should ordinarily include components for acquiring information on source and ventilation characteristics.

-- strategies for controlling indoor pollutant levels, whether in the context of conservation programs or for the purpose of reducing excessive levels within the general housing stock, should take account of the dependence of the performance of various control techniques on source and ventilation characteristics; moreover, consideration of the dependence of concentrations on housing type or location, or on the presence of specific materials or appliances, can focus control efforts much more effectively than would otherwise be possible.

Perhaps the most general conclusion to be reached is the need for continued work investigating the dependence of indoor concentrations on various factors, work that should be carried out in close cooperation with efforts to monitor indoor concentrations within the building stock, to understand the health effects of indoor pollutants, and to formulate strategies for their control.

Finally, it is worth mentioning that this summary of LBL work is not comprehensive, but indicates the main results of our efforts. I have referred to some of our group's publications, in particular the principal ones associated with the work summarized above. These efforts have been supported primarily by the Department of Energy's Office of Conservation and Renewable Energy, to a somewhat lesser degree by DOE's Office of Health and Environmental Research, in the Office of Energy Research, and to a yet smaller -- although still substantial -- degree by the Bonneville Power Administration, the

Environmental Protection Agency, and the Consumer Product Safety Commission. Continuation of research in the areas indicated above is dependent on the balance of funding in the future.

Particulates, Radon Daughters, and Their Control

I will now turn to a review of the state of knowledge of indoor particulate concentrations, both because this is appropriate to the structure of these hearings and because particulates represent a prime example of the need for the kind of characterization effort that I emphasized above. Along this line, I will address the question of interactions between particulates and radon daughters and the implications for control of either of these species. However, I will first touch briefly on the information now available on indoor particulates.

Knowledge of the sources, concentrations, and chemical composition of indoor airborne particulate matter is only fragmentary. Moreover, even more than for other indoor pollutants, the suitability of comparisons with outdoor concentrations or standards is questionable since measurements are often acquired on a different basis and the outdoor (national) standards simply cite total suspended mass, taking no account of differences in size or composition. Moreover, as will probably become evident in the second day of hearings, there are corresponding difficulties in ascribing health effects to particulate exposures, whether outdoors or indoors.

Still, it is known that indoor concentrations of total particulates or respirable particulates (those with size in the range of a micron or less) often approach or exceed outdoor levels or the standards that are applied outdoors. The strongest source of particulate indoors is cigarette smoking, to which almost the entire population is exposed either at home or elsewhere. Particulates also arise from any combustion appliance, from various types of materials indoors, and -- of course -- from the air that enters from the outdoors. However, the building shell can act as a significant barrier to entry of particulates, and -- in any case -- it is typically the particulates that are generated indoors that are of more concern.

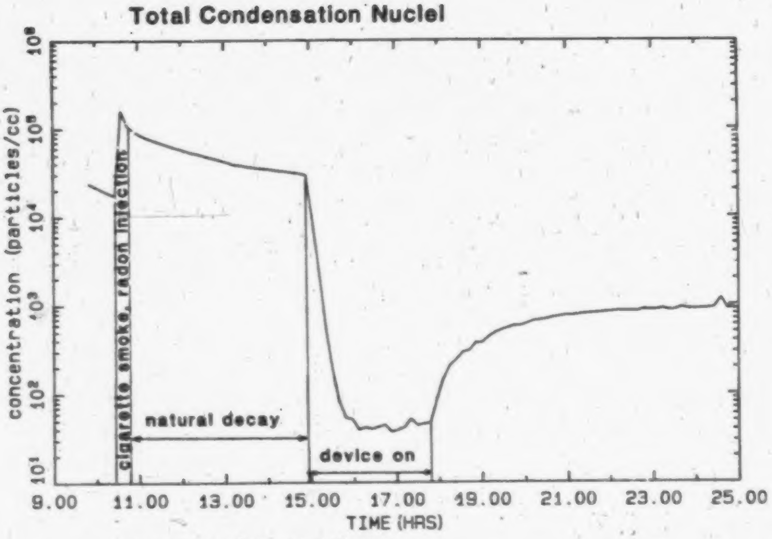
A modest amount of work has been performed in characterizing the chemical and physical form of particulate matter that is found indoors or that is emitted from various indoor sources. It is known, for example, that the particulates in indoor air due to cigarette smoking contain a large number of compounds, many known to be carcinogenic, and that these particulates -- like most found indoors -- are in the respirable size range. For the most part, combustion appliances generate a relatively small amount of particulates, but -- in some cases (e.g., wood stoves) -- their composition is such as to be of concern, and the presence of higher-than-average numbers of particles in the air may any case have significant implications for other pollutants that are present. Substantial work remains to be done to characterize the amount, size, and composition of particulate matter in indoor air. This will require substantial monitoring efforts in existing buildings and, perhaps even more important, fundamental studies of the behavior of particles indoors.

We are unable to say much about particulate behavior, even though -- as for the outdoor atmosphere -- it lies at the root of some of the main questions. For example, we know little in general about the interaction of particulate and gaseous species indoors. And although we do not expect the specific smog reactions that are so important outdoors to occur substantially indoors, there is every reason to suspect that gas-particle reactions can be important. This could include reactions between particulates and gaseous combustion products, condensation of organic compounds on particulates, and interactions between particles and radon daughters. The last type of interaction is known to have a profound effect on radon daughter behavior indoors and on the health effects associated with exposure to radon daughters. I will now turn briefly to these questions.

Unlike radon itself, a gas that does not interact chemically, the decay products (or progeny) are chemically active and can attach to airborne particles or to walls, can be collected efficiently in air cleaning devices, and can also deposit in the lung - either directly or along with particles to which they are attached - when they are inhaled. I point out two key factors in considering the importance of attachment of the progeny to particles: first, in the absence of particles, the progeny tend to stick to walls at greater rates, so that they cannot be breathed, but, secondly, a greater portion of the particles remaining in the air under such conditions remain unattached. The progeny that are unattached are thought to have a greater probability of causing significant radiation exposures (and hence added risk of lung cancer). Thus it is not clear whether low particle concentrations are an advantage or a disadvantage. In any case, a good deal of study is now being given to the determination of progeny attachment rates to particles in various size ranges, since this will in any case affect strategies for controlling exposures to radon progeny.

I can point specifically to work being performed at LBL's radon research house, a facility that was established to study the behavior of radon progeny (and which has also been used for a number of other studies). A key element in the particle/radon-progeny studies has been characterization of mechanisms affecting progeny concentrations, and these have included attachment to particles, attachment to walls, and removal by air-cleaning systems or devices. Study of air-cleaning has also been an interest of our group from the simple perspective of particulate control. An example of work that relates to both of these questions has been a recent study of the performance of a variety of stand-alone air-cleaning devices, as distinguished from those incorporated into a whole-building heating or cooling system. In these studies, we determined the effectiveness of these devices for removing particles in various size ranges and for removing individual radon progeny, using the unusual capabilities of the radon research house. Not surprisingly, the effectiveness of the several devices differed substantially. (See Figs. 11-12 and Refs. 27-28)

This points out a major gap in understanding the effectiveness of air-cleaning devices for removing particulates. If their effectiveness has been measured at all, this is usually limited to



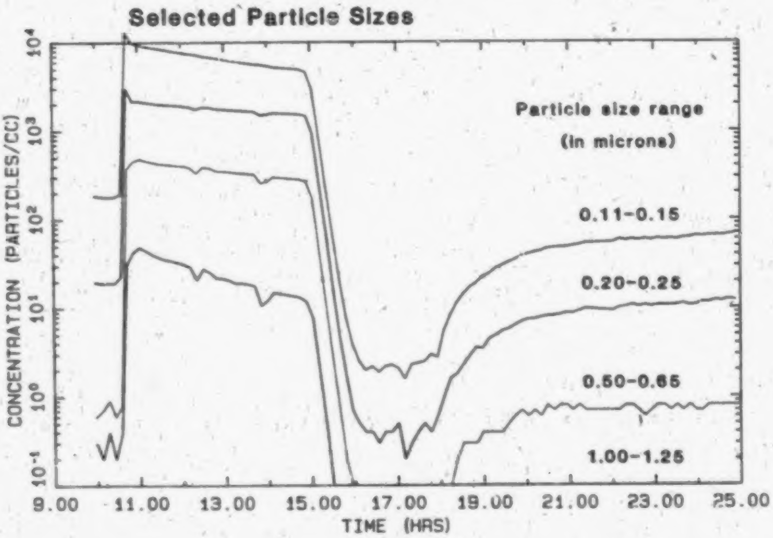


Figure 11 (top) Concentration profile of total particulates before, during end after operation of an air cleaning device containing a High Efficiency Particulate Air filter. These measurements are designed to evaluate the effectiveness of various air cleaning devices for control of particulate and radon progeny concentrations.
Figure 12 (bottom) Same as Figure 11, showing concentration profiles of particles in selected size ranges.

measurement in terms of total particulate mass, occasionally in terms of particle size, and virtually never in terms of the effect on particular chemical or physical species, e.g., organics or radon progeny. In general the overall effect of air-cleaning devices on the pollutants present in indoor air is simply not known. The effectiveness of such devices and in fact of any control technique will only be understood in the context of future research on the behavior of airborne pollutants indoors, giving due weight to the interactions that pollutants have with each other and with the building and its contents.

Indoor Air Quality Research Needs and Cooperation Requirements

Most will agree that a substantial amount of research remains to be done in the area of indoor air quality, and I have emphasized requirements for characterization of indoor pollutant behavior, which -- in turn -- is closely tied to understanding the implications of energy conservation measures for indoor air quality. A summary of research needs in the areas I have treated will make clear the strong connection between this work and that required for monitoring, health studies, and formulation of control strategies.

For each of the pollutant classes I have discussed -- combustion products, radon and its progeny, and formaldehyde and other organics -- and also for those I haven't treated -- spores, viruses, lead, asbestos, etc. -- further attention has to be given to the origin of the various species, to their interactions once they are in the air, and to their removal by ventilation and other mechanisms. The balance of work remaining in these areas depends on the pollutant class:

-- combustion emissions have been adequately characterized for some appliances, but much remains to be done on the effects of combustion modification, on the effectiveness of local versus general ventilation, and on the interaction of these emissions with other species and with the building structure and air-cleaning techniques other than ventilation.

-- radon and its progeny are known to have a wide range of concentrations indoors, dependent mainly on entry rates, and future work ought to emphasize the potential for systematic identification of houses with high source strengths, the mechanisms for radon entry into houses, and the behavior of radon progeny indoors.

-- Formaldehyde and other organics are known to arise from a large variety of building materials, as well as from combustion processes, and the areas requiring study are the dependence of emission rates on temperatures, humidity, and ventilation rates, the potential for reducing these emission rates, and -- in the case of organics -- more effective monitoring techniques.

Elucidating these questions in the laboratory or in small numbers of homes often requires the development of sophisticated techniques for performing intensive and detailed measurements. At the other extreme, studying the dependence of indoor concentrations in the building stock at large requires simple, inexpensive monitors. The capabilities for development and characterization of such devices is an important element in programs for monitoring indoor air quality on a large scale, as discussed below.

Finally, the study of indoor pollutant behavior in general, and of the effectiveness of various techniques for controlling pollutant concentrations, constitutes the basis for formulating control strategies: techniques that require further study include modification of sources, emission reduction by sealants or local ventilation, and removal from indoor air by general ventilation, air filtration, or use of adsorbent materials.

Such work as I have described, which is emphasized by our group because of its connection with building design and operation, and hence energy conservation measures, is clearly connected with interests of agencies other than the Department of Energy (DOE): the Consumer Product Safety Commission (CPSC) is interested in effects of appliances, materials, and other products used indoors; the Environmental Protection Agency (EPA) has a definite interest in exposure to air pollutants, many of which are found indoors; and the National Institutes of Health (NIH) has an interest in the health effects of such exposures. Thus it would not be difficult to associate the EPA with monitoring, the NIH with health studies and DOE and CPSC with characterization, employing the terms used above. Yet these areas cannot be separated entirely, although the main interests of specific agencies or scientific disciplines can be defined generally. An example of the need for collaborative effort among the scientific community, and of joint support from the agencies, is the prospect of a large-scale program to characterize indoor pollutant concentrations, building-related factors, and occupant health in a sample of many thousands of houses selected across the United States.

A summary of what such a program might entail is given in an attachment to this statement. The objective would be to select a large "full sample" of housing in which a number of key pollutants are measured, using integrating passive samplers of the kind discussed above, in which building characteristics related to sources and ventilation rates are examined, and for which information on acute and chronic health effects of the occupants is acquired. In a subsample, more intensive measurements would be performed. Given our present knowledge of indoor air quality and the present state of the art in monitoring, the objective of this program would be to make a giant step forward in understanding the distribution of pollutant exposures among the general population, the association of these exposures with building-related factors, and the health effects that may be associated with these exposures. It would obviously require a strong collaborative effort, drawing on the full resources of the scientific community, and bringing physical and health scientists together to a degree that has not yet occurred in this area. The support and development effort required to move forward with this program could reasonably be carried forward with funding from normal healthy agency budgets. The main monitoring phase would probably require a specific appropriation.

Effective progress on this and other major elements in a vigorous program on indoor air quality has as a principal requirement substantial support from the federal agencies, as indicated in the second document that I have attached. The consensus of all studies of needs for indoor air quality research is that the main support for research per se can only be provided as a federal responsibility, and that this should be complemented in a very practical way by industry efforts and by state and local activities. But, presuming such federal support, coordination of the effort, for example in a national indoor air quality survey, is obviously necessary. This must entail cooperation at two levels: clearly the agencies themselves need a mechanism for identifying their principal responsibilities and for communication of research results, and secondly the research community itself could improve its own awareness and selection of the wide range of research projects required, while at the same time more effectively providing advice to the supporting agencies. The first requirement can be satisfied by resurrection of an interagency committee on indoor air quality. Constitution of a national scientific committee on indoor air quality would help the research community keep track of research progress and priorities, while advising the agencies effectively.

How to create effective cooperative mechanisms is a topic on which I will not say more. In fact, I would offer the caution that coordinating mechanisms be defined in a way that still manages to encourage initiative and creativity at the level of both the federal agencies and research groups. Progress in understanding indoor air quality is like any public issue that has a major scientific component. Resources must be devoted to basic scientific work, to large-scale information gathering, and to technical and policy decisions on appropriate strategies for dealing with the basic issue, which in this case is the public health consequences of indoor air pollutants. The best progress in each area can be had by charting a course of research that effectively addresses the main questions, expecting active cooperation among the participants and anticipating that there will be some modest overlap. Rather than being waste, such cross-fertilization can give rise to new points of view and novel approaches that will ultimately speed us toward our objectives. These are characterization of the extent and health implications of indoor pollutant exposures, as well as the factors affecting indoor pollutant concentrations, and formulation of strategies for assuring good indoor air quality.

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A NATIONAL SURVEY OF INDOOR AIR QUALITY

Our basic understanding of indoor air pollutant concentrations and how they may be measured conveniently has now advanced sufficiently to warrant the beginning of efforts to conduct a national survey of indoor air quality, carried out on an interagency, interlaboratory basis. The objectives of this survey would be to determine average concentrations of key pollutants to which the U.S. population is exposed, to delineate the range of concentrations and their dependence on building features, geographic location, and use patterns, and to use this dependence on concentration to examine the health effects of key indoor pollutants.

The differing objectives correspond roughly to the differing interests of various Federal agencies. For example, it is the dependence of indoor pollutant concentrations on building characteristics and ventilation (rates and patterns), both connected to energy use, that gives rise to Department of Energy (DOE) interest in this program. Environmental Protection Agency (EPA) interest arises directly from the question of indoor human exposures and their contribution to total exposures. Similarly, the National Institutes of Health (NIH) has an interest in efforts intended to delineate the connection between health effects and indoor airborne pollutants that may be causative agents.

Accomplishing these objectives will require substantial efforts on the part of the entire indoor air quality research community and the support of the several Federal agencies with an interest in indoor air quality, as well as the cooperation of private-sector energy research institutes and analytical laboratories. Members of the research community have been holding discussions among themselves and with Federal agencies and other entities on how such a national survey might be undertaken. This survey is generally acknowledged to be a principal element in national efforts to characterize indoor air quality.

Technical Approach:

The overall structure and major elements of such a program are yet to be determined. The major thrust of the program will be the monitoring of key indicator pollutants, using simple techniques, in many thousands of homes across the country, at the same time acquiring information--based on questionnaires--on the homes being monitored and on the health of the occupants. The program would provide basic information in three areas: pollutant concentrations, the various factors that affect them, and the health effects caused by them.

Considering the monitoring techniques available or soon to be available, the pollutants measured will presumably include nitrogen dioxide, radon 222, formaldehyde, and possibly carbon monoxide, but others may also be included in the full survey sample. In addition, more intensive investigations will be undertaken in a subset of the full sample, with several purposes: first, to obtain at least a modest amount of information on a more complete pollutant spectrum (including, for example, particulates and volatile organics) than is practical in the full sample; second, to help establish a basis for interpreting the results from the full sample, i.e., by using the subset to study the dependence of concentrations on time, environmental conditions, use patterns, and detailed building and ventilation characteristics; and, third, to obtain more detailed health-related information, as appropriate.

Major organizational questions include scientific direction of the effort, mechanisms for interagency support for the study, and the involvement of utilities and private-sector laboratories in actually performing the full sample survey. The indoor air quality research community is highly diverse, and ultimately many parts of it would be involved in this program. For the time being, members of a number of U.S. research groups are engaged in discussions about the form, funding, and implementation of such a survey.

Key objectives for the next two years appear to be:

1. design and planning of the survey and performance of supporting development work that may be required; and
2. implementation of a pilot study using the techniques that are tentatively selected for the main survey.

During the second year, in parallel with a pilot survey, substantial effort will be devoted to selection of the main study sample, final design of the survey, including the protocols for both the full sample and the intensive subsample(s), and creation of the cooperative infrastructure for performing the measurements. Any development required will be performed in parallel with these efforts. On completion of this preparatory work, the main survey itself can actually be conducted and the results analyzed. The full survey sample will have three major elements:

1. monitoring of the key pollutants of interest, such as those indicated above, relying primarily on simple passive samplers, many of which are already available;
2. characterization of the buildings being monitored, including visual inspection of key source and ventilation-related characteristics, and information on use patterns, all intended to investigate the correspondence between pollutant concentrations and factors such as sources, ventilation rates, other removal mechanisms, and occupant behavior; and
3. survey of the health of the occupants, including both acute and chronic health information relying on epidemiological survey instruments of proven design; thought is now being given to cluster sample approaches that would focus efforts in a number of geographic areas, with stratification of the sample in each cluster based on building and population characteristics. However, to capture the full range of pollutant dependencies, the full sample may need a component that is dispersed beyond a small number of clusters.

These three elements can be related directly to the interests of the Federal agencies with principle interests, although ultimately all of the components are interrelated. The intensive subsample studies would be designed to investigate each of these elements in more detail, as necessary, to maximize the breadth and reliability of results from the program.

Program Implementation:

This overall effort will take 4 to 5 years, with a total funding of $10 to 15 million over this period. Annual funding of about one-tenth this amount (i.e., $1-1.5 million or so a year) can reasonably be expected to be taken out of ordinary agency funding for indoor air quality, provided the agencies have vigorous efforts in this area. However, about half the total effort will be devoted to procurement for, and conduct of, the main study itself, requiring a specific allocation of funds.

The base funding indicated above from the various agencies will support the initial objectives indicated above (design and planning of the survey, plus conduct of a pilot study) and will provide continued technical support of the main survey effort from the principal scientific groups. Procurement for the main survey will begin during the second year, and the main monitoring effort will be undertaken during the third year, with completion by the fourth. Analysis and interpretation of the data will be performed periodically as results flow in, with completion of analysis during the fourth (and fifth) year.

Substantial care has to be taken in the creation of an effective interlaboratory approach to accomplishing this key element of a vigorous program of indoor air quality research. A notable aspect of the program will be the active collaboration of different scientific communities to accomplish the characterization, monitoring, and health-related objectives. The work will undoubtedly require the guidance of a national scientific advisory board, as well as the active assistance of the various agencies, presumably coordinated through an interagency committee. The next step is to define more fully a conceptual design for the program as a whole, paying specific attention to: the pollutants to be monitored, instrumentation selection, statistical design, selection of full and intensive samples, characterization of building-related factors, acquisition of health information, etc. Once this is done, the various scientific groups can begin explicit effort to carrying out the program objectives.

ATTACHMENT 2 Nero

FEDERAL RESEARCH NEEDS ON INDOOR AIR QUALITY AND ENERGY CONSERVATION

Introduction

A major part of human exposure to air pollution occurs indoors to the general population in their own houses and offices. Exposures of comparable importance occur due to outdoor pollution and to occupational exposure from specific work-related emissions. In the United States, thousands of deaths, and a much larger incidence of sickness or acute distress, occur annually due to outdoor and occupational exposures. This has been the main reason for the assignment of substantial and explicit responsibilities for controlling these exposures to the Environmental Protection Agency and to the Occupational Safety and Health Administration. The amount of illness and death arising from indoor exposures appears to have a similar scale. This has prompted a number of agencies to begin research programs over the last decade or so with the purpose of either characterizing or understanding how to control indoor air pollution in respects that are consistent with the missions of each agency. In spite of the importance of this question, the total federal allotment to research on indoor air pollution is only a few million dollars per year, a small fraction of the funds devoted to programs on outdoor or occupational exposures. This commitment is extremely small considering the thousands of deaths per year (and larger incidence of illness) that can be attributed to exposure to indoor air pollutants. Considering the complexity and importance of the indoor air pollution question and considering the potentially adverse impact on indoor exposures of new products and building designs (especially those intended to save energy), research efforts in this area ought to be increased significantly. Explicit acknowledgement of the special roles of several agencies in this area would also be helpful.

Considering the significance of indoor exposures, substantial concern arises from the potential effects of energy conservation measures on air quality in the indoor environment. One of the most popular and cost-effective means of conserving energy is weatherization--the reduction of outdoor air infiltration--a measure that can result in increased concentrations of indoor-generated pollutants. In larger buildings ventilation rates are reduced to save energy with similar effects on indoor air quality. Thus, elevated indoor air pollutant concentrations, which in some instances are already high enough to be a problem, may result from the implementation of certain energy conservation measures. Unless specific controls are simultaneously applied, or intervening factors occur, either the pace of building energy conservation programs will be constrained or indoor air quality will suffer. Coping with current levels of indoor pollutants, which now vary over thousand-fold ranges within the housing stock, and with the potential effects of energy-conservation measures, requires substantial attention to indoor pollutant behavior. This requires characterization of: 1) indoor sources, and the factors affecting emission or entry rate, 2) the effect of ventilation rates and patterns, including questions of local versus general ventilation and of ventilation effectiveness, and 3) removal due to other mechanisms, such as interactions between pollutants and attachment to walls or HVAC system components. In the context of such work, we can understand the dependence of indoor concentrations on building-related factors, including energy-conservation measures and techniques to control indoor pollutant levels. This understanding enables us to proceed with energy conservation programs while providing for good indoor air quality.

Indoor pollutants can arise in different ways, and the origin of a particular pollutant affects the applicability of particular control strategies.

— Pollutants enter from outdoors. All pollutants found in the outdoor environment (e.g., NO_x, SO_x, CO, TSP, microbial spores, dust, pollen, etc.) can infiltrate indoors. In addition to outdoor air, soil gases (e.g., radon) may find their way directly into buildings in significant quantities.

— Pollutants are generated by indoor activities. Domestic sources include routine cooking, cleaning, smoking, hobbies, use of sprays, and emissions from the human body. Some heating appliances, such as unvented kerosene or gas space heaters, can emit very large amounts of pollutants into the indoor environment.

— Pollutants can be emitted from building construction materials. Building materials, including concrete, wood products, paint, plastics, and insulation material may emit a variety of pollutants, including radon, asbestos, formaldehyde, and other organics.

As an indication of the last question, the status and general applicability of control via ventilation, air cleaning, source removal/exclusion, and source substitution are summarized in Table 1. An additional method, education of the inhabitants, does not involve a system, as such, yet may well be an effective approach in controlling indoor air quality. These various control methods are not always independent. Finally, any indoor air quality control strategy should satisfy health, safety, comfort, and energy conservation objectives while minimizing costs and changes in the way of life.

Work at the Department of Energy, which has the most apparent responsibility for research on energy conservation and indoor air quality, has emphasized the effect of building design, including energy-related features, on the sources, concentrations, behavior, and control of indoor pollutants. As indicated below, the primary roles of the various agencies appear to differ from one another, and cooperation is required to avoid gaps or an undue amount of overlap in the areas being investigated. In addition, industry has a substantial role to play in this area, focusing largely on their particular interests. Historically, federally-funded research has led industry efforts on indoor air quality. This is not surprising since--unlike those of industry--federal efforts have an explicit interest in detailed characterization and exposure monitoring, applied in a consistent manner to the various aspects of indoor air pollution. Industry has a clear role in evaluating its own products in a manner that is consistent with the developing picture on indoor air quality.

Table 1. Indoor Air Quality Control Techniques.

Control Method	Comment
Forced Ventilation	Widely used in industrial, institutional, commercial, and transportation environments. May require substantial energy for heating and cooling, or may improve energy efficiency, depending upon control system.
Natural Ventilation	Efficiency as a control strategy is not well documented, but is expected to vary considerably. Noise considerations and high indoor pollution levels may limit effectiveness.
Infiltration	Ordinarily unintentional air leaks; energy waste is closely associated. Widely used in residential environments.
Local Ventilation and Heat Exchangers	Efficient control strategies for both small and large buildings; research needed to quantify the efficiency of each strategy.
Continuous Air Cleaning	Pollutant dependent; effectiveness requires further documentation. Contaminant control devices are often large, expensive, noisy and require maintenance.
Source Exclusion (entry prevention) Source Removal	Can be very effective but requires extreme care in application to assure effectiveness; retrofit application may be very costly. Research needed to improve effectiveness.
Source Substitution	Has not been widely used; feasible if the source is substituted with an equally functional alternative that does not generate indoor pollutants.

The Need for a Government Role in Indoor Air Quality

Based largely on research that had been performed during the 1970's, several international, national and industry or standard-setting organizations have recognized the importance of the ongoing work on indoor air quality to the extent that commitments were made to workshops, expert studies, and substantial research programs in this area. As examples, a World Health Organization working group report in 1979 said:

> "Since man spends up to 70% of his time (indoors) and air quality indoor was usually somewhere between that outdoors and in the occupational environment, further studies should be made on indoor air quality, the factors that affect it, and its role in the total adverse health effects" of air pollution. "Studies on the nature and rates of emissions of indoor contaminants, as well as the rates of their absorption and inactivation, are urgently needed..."

A National Academy of Sciences panel on indoor pollutants, reporting its findings in 1981, recommended:

> "Responsibility for conducting a well-coordinated investigation of influence of building design and operational factors on the concentrations of pollutants in both residential and commercial facilities should rest with federal government, assisted by the appropriate professional and scientific organizations," with the initial focus of investigation on:
>
> — "the effects of reducing infiltration rates in existing buildings on concentrations of indoor-generated air pollutants;
>
> — the effects of materials of construction and furnishings on indoor-pollutant content;
>
> — the difference in air distribution, diffusion, mixing, etc., associated with the use of different climate-control systems;
>
> — the effectiveness of air-cleaning systems in capturing pollutants in recirculating air."

The need for a greater federal role in research on and assurance of indoor air quality had also been called to the public attention in 1979 by an Office of Technology Assessment report that said:

> "It is now clear that indoor levels of several important air pollutants can be as high or higher than outdoor levels." The "low level of [Federal] effort is particularly difficult to understand."

A 1980 report to the Congress by the Comptroller General suggests a reason:

> "While Federal officials agree that indoor air pollution poses a potentially serious health problem, they have been reluctant to invest resources to study it because they lack clear responsibility for addressing the problem."

Finally, in respect to the role of industry, ASHRAE said in 1982 that:

> "While some incentives do exist in the private sector to conduct research and develop products related to indoor air quality government has an important leadership role to sponsor research on indoor air quality, its human health consequences, and to advance the technology of contaminant control. No single professional society, manufacturing association, trade association, or branch of industry has the comprehensive interest, resources and competence in indoor air quality technology to insure that a well-funded systematic research program is conducted."

The message is clear: That indoor air pollution can have substantial health consequences, and that a more substantial and comprehensive research program of: 1) characterization (of sources, pollutant behavior, and control techniques--including the effect of various building design features), 2) monitoring, 3) health studies, and 4) control strategies must be undertaken through a coordinated Federal effort. As ASHRAE says, "once [Federal] research has identified the needs for better solutions for improved health, the private sector will respond with improved, innovative, cost-effective solutions."

General Responsibilities for Research on Indoor Air Quality

Several Federal agencies have implicit or explicit responsibilities for research on indoor air quality. The significance of current levels of indoor pollutants and the potential for increases due to measures that increase the efficiency of energy use in buildings caused two agencies, the Department of Energy (DOE) and the Environmental Protection Agency (EPA), to start significant research efforts on indoor air quality. (Both efforts were substantially decreased in size in 1981, exactly the opposite of the recommendations cited above.) Because of its explicit responsibility for research on energy conservation, and its specific role in research on building design and performance as related to energy, DOE has established a substantial and unique competence to examine the factors affecting indoor pollutant concentrations. This focuses generally on sources, removal mechanisms and control techniques, and specifically on building design, ventilation rate (or its reduction), and air-cleaning systems. On the other hand, because of its general mandate for environmental protection and its specific responsibility for and competence in control of outdoor ("ambient") air pollution, the EPA has a substantial role to play in monitoring, risk assessment, and--together with other agencies and industry associations--formulation of control strategies.

Most of the research needs cited above by the National Academy of Sciences and much of those cited by ASHRAE fall squarely into the area in which DOE has established unusual competence, i.e., detailed research characterizing indoor pollutant behavior and its relation to energy-efficient building design. This competence includes not only laboratory investigations and field testing of the influence of ventilation on indoor air quality, but also the implications of this work for design of large-scale field studies. This is true even though wide-scale general monitoring and associated regulatory responses (except to the extent this involves building design parameters, per se) must be construed to be a joint responsibility of the federal agencies.

Focusing on DOE and EPA is not intended to minize the responsibilities of other agencies, some of which, in particular the Consumer Product Safety Commission (CPSC) and the National Institute of Environmental Health Sciences (NIEHS), have made substantial commitments to work on indoor air quality. In effect, a spectrum of work is required in this area, and several agencies have explicit responsibilities for various aspects of pollutant characterization, monitoring, health studies, and formulation of control strategies. As indicated above, DOE is understood to have responsibility for examining how changes in building design (whether construction materials, appliance, or ventilation techniques) that are intended to save energy also affect indoor air quality. DOE has therefore developed a unique capability for examining how proposed or possible changes in building design affect indoor pollutant concentrations.

The other side of the fundamental research picture is to investigate the health effects of indoor pollutants using epidemiological studies, clinical and animal studies, etc. While a variety of such work relevant to indoor exposures has been performed by several agencies (e.g., parts of DOE have historically investigated health effects of radiation, modeled exposures due to combustion products, etc.), NIEHS in particular has undertaken substantial basic work on the health effects of indoor pollution as a general problem. The NIEHS work is oriented toward exposure measurement and health effects analysis at a more fundamental level than the monitoring and risk assessment generally associated with the EPA.

Another agency with responsibilities on indoor pollution is CPSC, which has a well-defined mandate to assure product safety. Consequently, materials and appliances used in buildings fall within their purview. In some cases, the CPSC's work related to indoor air quality is an examination of products after they become available. (For this reason, industry has a clear incentive to consider indoor air quality as one basis for developing products that will pass such an examination.) In other instances, CPSC could set performance requirements for new products. Such CPSC activities have required significant research efforts, sometimes in-house and at other times in cooperation with other agencies (such as DOE) that have developed a suitable capability because of a common interest.

Other agencies also have interests in indoor air quality. The Department of Housing and Urban Development (HUD) has a a clear interest in buildings, an interest that now lies more in the direction of implementation than toward research or assessment. The National Institute for Occupational Safety and Health (NIOSH) performs work on monitoring and control of exposures in occupational settings, a responsibility that can be construed to apply to commercial buildings (including office environments) and, in any case, involves capabilities that are relevant (if not directly applicable) to monitoring of indoor pollutants.

HUD's interest in implementation, CPSC's responsibility for product safety, EPA's mandate for environmental protection, and DOE's investigation of the effects of building design on indoor pollutant concentrations is indicative of an ambiguity in responsibilities for indoor air quality research or--in this case--associated measures for public protection. Such ambiguity is by no mean peculiar to indoor air quality, but rather is characteristic of other questions of health or environmental protection. The agency interests just named all lie in the are of formulating strategies to assure adequate indoor air quality. They reflect genuine and appropriate, but differing, responsibilities of the various agencies. And, although EPA can (and ought to) be construed to have a general mandate to protect the public, the other entities named have differing areas of responsibility in respect to contributing to this protection which--with proper acceptance of these responsibilities and an appropriate level of coordination--can complement each other, rather than clash. Moreover, with these differing responsibilities are associated specific and substantial capabilities that, if fully utilized, will contribute to a sounder and more timely program of research and protection of the public.

Research on Indoor Air Quality as it Relates Building Design and Energy Conservation

The central DOE responsibility has been to characterize the dependence of indoor pollutant concentrations on building factors related to energy. To a greater or lesser degree, every pollutant has such dependence, if only through the ventilation rate and other factors related to the building heating or cooling systems. In addition, many of the pollutant entry rates (for combustion products, radon, and organics) are affected directly by building features that are energy related--including again, ventilation conditions. The characterization of specific control techniques is an integral part of this work. Thus, central to effort on energy conservation and indoor air quality should be characterization of the dependence of indoor levels on sources, ventilation rates, and other removal mechanisms (e.g., a filter in the HVAC system or an energy recovery system). Much of this can be accomplished by laboratory-based studies, supported by selected field efforts that determine in practical situations the effect of energy-related features (e.g., infiltration reduction). This intermediate level of investigation, i.e., moderately-intensive laboratory studies and selected field efforts, is appropriate in direct connection with the programs on energy conservation in buildings, such as those carried out by DOE's Office of Conservation and Renewable Energy. It contrasts with broad-scale monitoring programs (of either DOE or EPA) or more intensive pollutant characterization studies, such as those carried out by the Office of Health and Environmental Research. Associated with the efforts on conservation should be a modest effort devoted to: development of simple monitoring techniques (which are useful for the selected field studies just mentioned), design of larger survey efforts (which would actually be performed together with others, e.g., as part of a national survey), and construction of a data base on house features and ventilation/ pollutant measurements that would constitute a functional model of the housing stock.

The work just mentioned is necessarily supported by more fundamental characterization efforts, such as those funded by DOE/ER/OHER on radon behavior, by efforts to simulate indoor air pollutant behavior by developing realistic physical models, and by examining the potential health effects of indoor pollutants as a partial basis for selecting acceptable building design features.

Note that several of these efforts, some of which have been supported by DOE until now, provide connections with other agencies, e.g., survey design and health risk assessment, both of which are related to NIEHS and EPA. The data base development, in addition, would directly involve industry organizations.

The research needs set forth below begin with projects that are explicitly related to energy conservation in buildings, then go on to basic characterization or health studies that support this work. Each of these areas has been the subject on continuing work at Lawrence Berkeley Laboratory or is a developing area in which new effort is appropriate.

Building Energy Conservation and Indoor Air Quality

Radon --laboratory and field measurements of radon sources and concentrations in conventional and energy-efficient housing; identification, through geographic and geologic assessment, using aerial radiometric data, of regions in U.S. likely to have high radon concentrations; experimental study of radon entry into houses and of associated control techniques. (Work in this area is now supported by DOE/CE, and is complemented by support from DOE/ER/OHER on radon daughter behavior and from Bonneville Power Administration [BPA] for FY83.)

Residential combustion appliances --characterize pollutants emitted by indoor combustion processes, emphasizing study of concentration behavior as affected by ventilation conditions. Examines emissions from gas stoves/ovens, unvented gas-fired heaters, kerosene heaters, and wood stoves. (Work in this area is not now supported by DOE/CE; related efforts are being carried out for DOE/ER/OHER, described below, and CPSC.)

Building material emissions --measure emissions from elected building materials and correlate with observed concentrations in home and office environments, examining dependence of emissions/concentrations on ventilation rates, humidity, and temperature; instrumentation development. (This work, to which renewed efforts have been devoted in the last year, does not have commitments for support beyond this calendar year.)

Passive samplers --develop low-cost, portable, usually passive, samplers suitable for measuring indoor air quality in research and energy-conservation programs; test and evaluate commercially-available monitors for suitability in indoor air quality monitoring; see also survey design, below. Development or characterization of monitors for NO_2, formaldehyde, CO, water vapor, etc. (DOE/CE's support of these efforts and of LBL's passive monitor test facility is being closed out.)

Control techniques --evaluate the energy performance, contaminant control capabilities, and economic performance of indoor air quality control techniques; assess feasibility of new techniques, emphasizing study of ventilation and active air cleaning systems. Includes study of air-to-air heat exchangers, filtration and washing systems, other heat recuperation devices. (This work has no commitment of funding from DOE/CE beyond FY83; heat exchanger work for DOE is being closed out. Short-term funding from DOE/EP, BPA, and EPA extends partially into FY84.)

Survey design --examine application of passive monitor packages in connection with energy-conservation programs or other large-scale survey programs; formulate approaches to statistically-valid selection of monitoring sites, interpretation of data, and handling of samplers; support for specific DOE programs, as well as large-scale programs in which DOE participates, such as a national survey of indoor air quality. (This work has no current funding.)

Concentration of indoor pollutants data base --collect existing data from measurements of indoor pollutant concentrations, ventilation rates, and housing characteristics in a user-oriented data base. (This effort is expected to be supported jointly by DOE, EPRI, and GRI.)

Undertaking work in the foregoing areas would require a higher level of funding than has been forthcoming in the last two years from DOE/CE.

Basic Characterization and Health Studies

Indoor air pollution health effects --characterize indoor air pollution and develop strategies to make assessments of health and exposure implications of indoor air pollution, especially as affected by energy-related features; has emphasized combustion products, with some assessment of radon risks; now emphasizing overall indoor air quality risk analysis, with specific interest in approaches to improving information on health effects of combustion products, radon progeny, and organics. (Continued support from DOE/ER/OHER.)

Radon characterization --investigate through laboratory and field studies the behavior of radon and radon progeny; conduct studies in a research house of attachment of radon progeny to particles and deposition on indoor surfaces; related instrumentation development, numerical modeling, and studies of air movement, all oriented toward influence of building design factors. (Continued support from DOE/ER/OHER.)

Indoor air quality modeling --formulate elements of a multi-chamber residential indoor air quality model capable of realistically treating the various sources of indoor pollutants and their transformation, transport, and removal as affected by building design and ventilation/air cleaning systems. (This work has no current funding.)

Indoor organic pollutants --identify airborne organic contaminants, characterize their sources, and understand the relationship between building practices (use of particular materials and design of ventilation system) and increased exposures; develop methodologies for identifying and quantifying trace organic contaminants in indoor air. (This work has no current funding; except for DOE/CE effort on building material emissions to end this calendar year.)

Indoor air quality control techniques --evaluate control techniques for maintaining acceptable indoor air quality in buildings with low ventilation rates or high source strengths; attention both to fundamental removal processes and to commercially-available devices; includes design and fabrication of an environmental chamber for contaminant-control studies. (This work has one-time funding from DOE/EP, BPA, and EPA.)

Mr. FUQUA. Thank you very much, Dr. Nero.

I understand Mrs. Schneider wishes to submit some material.

Mrs. SCHNEIDER. Yes, regrettably, Mr. Chairman. I would like to ask unanimous consent if I might include in the record a few articles on indoor air for today's hearing.

Mr. FUQUA. Without objection.

Mrs. SCHNEIDER. Thank you.

[The information follows:]

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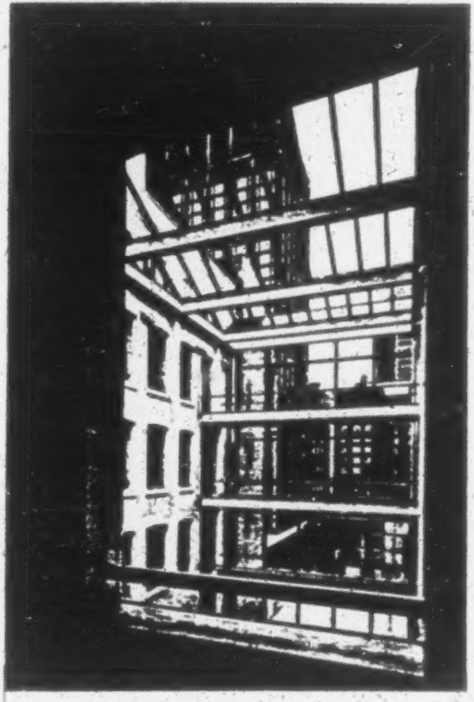


New Health Hazards In Sealed Buildings

Findings from recent research.
By Elia and Theodore Sterling and David McIntyre

Adler & Sullivan's Wainwright Building in St. Louis, constructed in 1891, contained all of the new technical elements that would become standard features of the high-rise office for the next 50 years: raft footings, fireproof tile covering structural steel, movable interior partitions, and fully operable windows for ventilation and daylighting. The Wainwright Building represented Louis Sullivan's deliberate attempt to create a special form for the multistory office block.

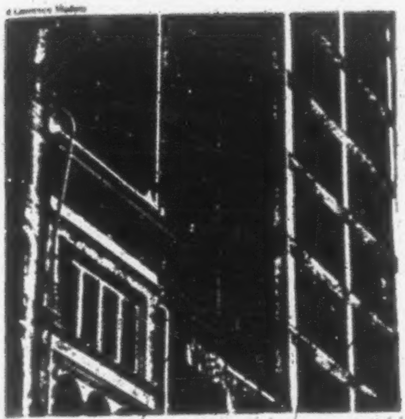
However, more importantly, the Wainwright offered a supremely logical solution to the technical and environmental problems important to the success of this new building type, the large office block. It introduced working and workable structural use of the steel frame; building anchoring techniques; provisions for heating, ventilation, and airconditioning; provisions for daylight penetration into individual room type offices; fire safety; vertical circulation by elevator.

The Wainwright functioned as an organic unit, providing light, air, and temperature control to the interior office and commercial space. The skylit ground floor and U-shaped plan of the office floors above maximized daylight penetration and provided outer exposure for all offices. Fully operable windows allowed adjustable fresh air ventilation, while steam radiators provided a clean, adjustable heat source. The Wainwright lacked the sophisticated, mechanical airconditioning system we now rely on, yet for nearly a century of constant use, until major renovation in 1981, it satisfied the spatial and environmental needs of office tenants.

The glass curtain wall, the deep floor plan, and the open office entered the American scene with a vengeance after the Second World War. These new architectural elements, combined with Willis Carrier's invention of the airconditioning system, provided the raw material from which the new mechanistic esthetic, the fully sealed, airconditioned building, evolved. One of the earliest buildings representative of the effects of these changes is Pietro Belluschi's Equitable Savings & Loan Building in Portland, Ore., opened in 1949. The Equitable Building was one of the first sealed, glass, mechanically serviced, and fully airconditioned office buildings in the U.S. In 1980 it was designated a National Historic Mechanical Engineering Landmark by ASHRAE and last year was honored with AIA's 25-year award (see July '82, page 84). Considered a landmark in the transition to sealed, glass, airconditioned buildings, its office space incorporated year-round airconditioning, good natural illumination and artificial light sources, sound control, attractive durable finishes, and a structure and utilities easily adaptable to change in office partitioning.

The design of the airconditioning system is of admirable simplicity. Each floor has its own fresh air supply through louvered intakes on the stair tower. Air is conditioned by a separate system on each floor. Incoming air is distributed through ceiling outlets. Return air is removed through slotted window sills into the plenum of the floor below. Perforated ceiling panels allow air, heated by the light fixtures, to be removed directly into the return air plenum. The building skin functions as a passive environment modifier. Heat absorbing glass was used not so much to reduce the solar heat load, but more to cut sky glare so that blinds or shades would not be needed for comfort. Similarly, double glazing was intended primarily to reduce cold drafts off exposed glass surfaces. Economically the use of a mechanical system was justified to allow an increase in leasable space over earlier window ventilated buildings. The Equitable was so successful that it became the model for a generation of American high performance, sealed office buildings.

Elia Sterling, research director for the Vancouver research firm of TDS Limited, is coauthor of the forthcoming book, *Modern Buildings and the Public Health*. **David McIntyre** is senior researcher for TDS Limited. **Theodore Sterling** is a professor, faculty of interdisciplinary studies, Simon Fraser University, Burnaby, British Columbia.



But much of its success was based on a variety of conditions that no longer exist for the subsequent generation of sealed buildings, including stable, mostly natural materials and durable interior finishes; lighting by cold cathode tubes with good color balance, no flicker, and minimal ultraviolet radiation emissions; a constant supply of fresh, outside air; an airconditioning system designed for good circulation by placing exhaust returns under the windows near the floor with supply vents in the ceiling; perforated ceiling panels allowing heat to escape from the lighting fixtures directly into the return air plenum, and an abundance of inexpensive energy that frees the design from constraints imposed by climate.

With the rapid rise of energy costs in the 1970s, which brought to an end the era of the high performance, sealed building, the search began for new design solutions responding to energy constraints and performance requirements. The Gregory Bateson State Office Building in Sacramento, Calif., designed and implemented under successive state architects Sym Van der Ryn and Barry Wasserman, FAIA, is a prime example of recent energy conserving office buildings.

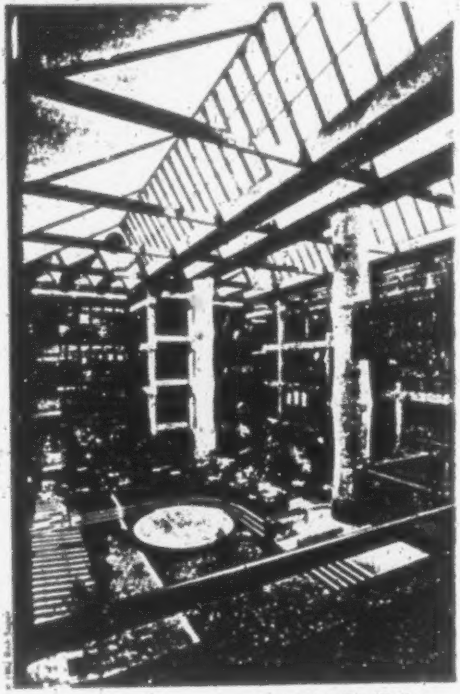
Approximately of the same scale as the Equitable Building (267,000 square feet), the Bateson was designed to respond to a wide variety of functional and esthetic constraints, including energy use and employee working conditions. Wasserman has been described as uncommonly sensitive to the impact of workplace upon worker, often pointing out that employees spend more of their waking hours in the office than anywhere else and that lower level employees are particularly affected since they have so little administrative control over their own working conditions. The Bateson, like the Equitable, is for all practical purposes sealed, with the environment created and controlled by a mechanical system. The focus of the building is an interior atrium, designed as a flexible energy management device that redistributes heat and provides natural light to interior office space.

As a means to minimize energy use, the Bateson, like the Wainwright a century before, uses the structure and massing to passively control the indoor office environment. A massive, exposed concrete frame stores daytime heat and slowly releases it at night. The many terraces, setbacks, and re-entrant corners increase the surface area available for thermal transfer and provide daylight penetration. On the interior, the suspended ceiling has been eliminated to permit heat stratification and indirect ambient lighting. Solar collectors for hot water, computer monitoring of electrical use, and an underground heat storage system using 600 tons of rock are technological features integrated into the building to enhance energy conservation.

Despite the architects' desire to design an office environment sensitive to the needs of the worker, the Gregory Bateson has been plagued by environmental quality problems since it opened in 1982 (see Sept. '82, page 18). Complaints of respiratory, gastrointestinal, skin, and eye problems began soon after the first occupants moved in. Some occupants complained of suffering dizziness, loss of balance, occasional sore throat, and itchy skin. There were reports of unpleasant odors. Most complaints seemed to come from areas with the lowest ventilation rates. More complaints occurred when the ventilation system was operated only in the daytime than when operated around the clock. Complaints were sufficiently insistent to lead public health authorities to study conditions. In fact as a result of the problems, contractors, subcontractors, and suppliers have been sued and the state faces worker compensation and class action suits, claiming health damages from poor air quality inside the building.

Air quality tests conducted by the California Occupational Safety and Health Administration found slightly elevated levels of formaldehyde, carbon dioxide, and other pollutants. Fur-

Across page, glass wall addition to the Wainwright Building; left, detail of the curtain-walled Equitable Building; below, atrium of the Gregory Bateson California State Office Building.



gal spores were found present in the air exhausted from the rock bed thermal heat storage.

Inspection of the ventilation system revealed that up to 80 percent of the induction boxes (a strategic component that controls the mix of air to diffusers) were found to be defective. Office space divider partitions were identified as a major inducer of formaldehyde and contributors to air stagnation.

All indications pointed to inadequate ventilation and poor air circulation and filtration as the most serious sources of occupant complaints. By good fortune, declining energy costs have allowed the ventilation system to be put back on 24-hour operation, providing a maximum fresh air supply without severely increasing operating costs. Better ventilation has resulted in dramatic reductions in both complaints and contaminant levels. This solution, however, is not permanent. When energy costs again escalate, the increased cost will force the choice between comfort and energy conservation.

With the best of intentions (to provide optimum environmental quality conditions within the context of an energy conserving office building), the architects stumbled upon the dilemma of modern, airconditioned office buildings. Major changes in building technology and energy supply that have occurred over the past decade and are still in progress may reduce the capacity of airconditioned office buildings to provide conditions fit for human habitation. These changes have included sealed building envelopes; dependence on mechanical heating, ventilation, and airconditioning to provide acceptable thermal comfort and air quality; introduction of unstable synthetic materials, maintenance products, and finishes that off-gas toxic contaminants such as formaldehyde, chlorinated hydrocarbons, and respirable particles or that leave dust residues; dependence on fluorescent and other gas vapor lighting that emit nonionizing radiation and may be a major catalyst of photochemical reactions indoors; technological advances in office equipment such as photocopiers and video display terminals that emit radiation and airborn contaminants and may require specially designed environments for safe use; and increased cost of energy and possible shortages at times of greatest demand that have become major incentives for reduction of fresh air ventilation.

In many ways the sealed, airconditioned, energy conserving building with minimum ventilation resembles a submarine, in that its indoor atmosphere must be kept fit for human lungs through the extensive use of sophisticated, mechanical equipment. The quality of the ambient environment depends primarily on inside activities, and materials, and on ventilation procedures that clean and refresh the air. Filtration of many contaminants is often neither economically practical nor technically possible. For this reason many maintenance products containing volatile chemicals commonly used in buildings are no longer allowed in submarines. Air quality problems in sealed buildings and submarines differ in specific instances but are often similar in kind. For example, there is a parallel between experience in submarines where deadly phosgene gas was produced by accidental combinations of leaking gases and the failure of the ventilation equipment in the Bateson Building leading to increased exposure of occupants to formaldehyde and other fumes.

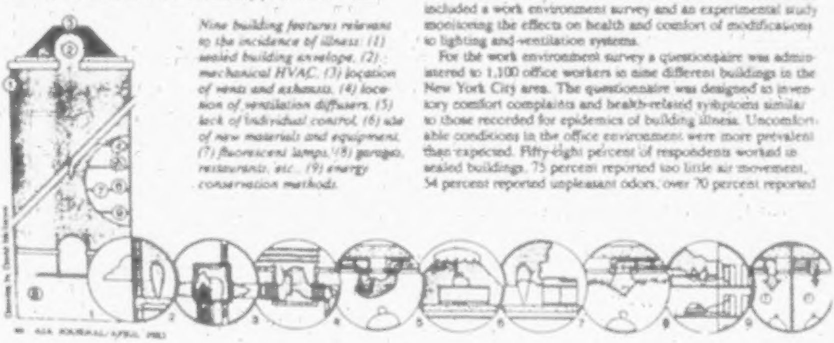
There are now nearly 300 investigations on record across North America of building-associated epidemics of illnesses and comfort complaints similar to those experienced by the occupants of the Bateson Building. Investigations were undertaken by government agencies, research institutes, and private consultants. Complaints ranged from minor to serious reports of reproductive system and pregnancy problems. Almost all instances have occurred in new or refurbished buildings in which conditions of ambient air and ventilation are completely mechanically controlled and lighting is supplied by fluorescent lamps. The overwhelming majority of these investigations coincided in time with a concerted effort to minimize building energy use by reducing fresh air ventilation rates and increasing the operational comfort ranges for acceptable temperature and humidity.

Tight building syndrome, insulated building illness, office building syndrome, and often simply building illness, all refer to epidemic complaints of illness or discomfort including headache, burning eyes, irritation of the respiratory system, drowsiness, and fatigue. The symptoms are generally experienced over an extended period of time and recur during occupancy in sealed buildings. The cause is rarely definitely determined, but is often suspected to be related to components of the building or air supply system. A few of investigated epidemics have been explained by specific causes such as carpet shampoo residues, glass fiber from ducting systems, asbestos, or formaldehyde. (Although smoking has been considered in nearly every investigation, no data have been presented that link smoking in buildings to health related complaints.)

In most investigated buildings, specific causes for symptoms have not been determined, yet many investigations have concluded the symptoms to be related to components of the building, particularly the ventilation system, operated at minimum ventilation rates.

In 1979 with the collaboration and support of the Legal Services Society of British Columbia and the British Columbia Government Employees Union in Vancouver and the Office and Professional Employees International Union in New York, TDS Limited began evaluating the effect of contemporary buildings on the health and comfort of office workers. This research has included a work environment survey and an experimental study monitoring the effects on health and comfort of modifications to lighting and ventilation systems.

For the work environment survey a questionnaire was administered to 1,100 office workers in nine different buildings in the New York City area. The questionnaire was designed to inventory comfort complaints and health-related symptoms similar to those recorded for epidemics of building illness. Uncomfortable conditions in the office environment were more prevalent than expected. Fifty-eight percent of respondents worked in sealed buildings, 75 percent reported too little air movement, 54 percent reported unpleasant odors, over 70 percent reported



Nine building features relevant to the incidence of illness: (1) sealed building envelope, (2) mechanical HVAC, (3) location of vents and exhausts, (4) location of ventilation diffusers, (5) lack of individual control, (6) use of new materials and equipment, (7) fluorescent lamps, (8) garages, restaurants, etc., (9) energy conservation methods.

that the temperature was either too cold or too hot, 63 percent reported the air too dry, and 74 percent reported the air too stuffy. Building illness symptoms experienced more than once a week were also prevalent: 37 percent reported headaches, 31 percent reported fatigue, 39 percent reported sleepiness, 31 percent reported nasal irritation, and 34 percent reported eye irritation.

A consistent association was found of all relevant symptoms with ability to control ventilation. A more detailed evaluation of the work environment survey (reported at the recent Second International Conference on Building Energy Management) showed building illness symptoms to be significantly associated with ventilation, air movement, and lighting. As could be expected, of the nine office buildings surveyed, fewer health and comfort complaints were reported in buildings with functional windows. This "I can open the window" effect agrees with other studies. In 1982, pollster Louis Harris conducted "comfort and productivity" survey (commissioned by Steelcase) that found 46 percent of office workers believe air circulation through open windows is better than in offices where only the HVAC system circulates the air. The study also found a profound negative impact on the comfort of white collar workers of the contemporary office workplace and concluded that office comfort has a direct impact on job performance.

An experimental study was undertaken to determine the effect of ventilation and lighting on symptoms reported by occupants of one sealed building. Office workers in the sealed building were paired with occupants of an older building with operable windows. A comparison of symptoms showed 60 percent more complaints of eye irritation, 25 percent more complaints of headaches, and 40 percent more complaints of sleepiness and fatigue among occupants of the sealed building. The cause was suspected to be indoor-produced smog generated by ultraviolet emitting, full spectrum (sunlight simulating) fluorescent lighting impinging on indoor pollutants. Ultraviolet radiation is known to enhance the production of photochemical oxidants, a major component of atmospheric smog believed to be responsible for eye and respiratory irritation.

Next, symptoms were monitored while experimentally modifying lighting and ventilation conditions. In a blind test (subjects were not aware that conditions were being modified) the ventilation was increased to the maximum fresh air supply, and in half the offices the existing full spectrum lamps were replaced by cool white lamps. When only ventilation was increased, eye irritation diminished by 7 percent; when only lighting was changed, eye irritation diminished by 8 percent; but when both lighting and ventilation were modified, eye irritation diminished by a significant and substantial 32 percent.

All the necessary conditions exist in offices to produce photochemical smog— ultraviolet radiation (from fluorescent lamps and photocopiers), formaldehyde (off-gassing from particle board, insulation, and other materials), hydrocarbon vapors (from infiltrated auto exhaust and off-gassing from paints and plastics), benzylic monoalkylbenzenes including toluene and styrene (ingredients coming from glues, solvents, and cleaning materials), and even trichloroethylene (contained in white-out materials used by typists). Thus the decreased eye irritation could very well be the result of reduced photochemical smog production when ultraviolet radiation is decreased and fresh air supply increased.

Overall, we have identified nine features common to office buildings where health and comfort have been problems.

- A sealed building envelope: Generally the amount of fresh air drawn into a mechanically, environmentally controlled building is minimized, as it is energy efficient to recirculate as much of the building air as possible.
- Mechanical heating, ventilation, and airconditioning: The HVAC system aids dispersal throughout a building of the many irritants and pollutants generated by materials and equipment. The system also may incubate and spread fungi, bacteria, and viruses. (A mechanical ventilation system was, in part, responsible for the spreading of Legionnella Pneumophilia bacteria that caused 21 deaths in the incident of legionnaires disease at the Bellevue Stratford Hotel in Philadelphia in July 1976.)
- Location of vents and exhausts: Air supply vents can introduce outdoor contaminants into a building. For example, supply vents located overlooking a busy street or transit stop are often the source of entry for auto or diesel exhaust. Also poor placement of supply and exhaust vents can prevent exhaust from escaping. Exhaust air may even be reintroduced directly back into the air supply.
- Location of ventilation diffusers: Both inlet and exhaust diffusers are commonly located in the ceiling. This often creates stratification and short circuiting of supply air at the ceiling level, which may result in pockets of dead air and poor circulation.
- Lack of individual control over environmental conditions: All people are not equally comfortable in the same environment. Elimination of the possibility to modify the environment tends to contribute to discomfort, stress, strain, and minor health problems.
- Use of new materials and equipment: Synthetic materials and modern office equipment as well as the industrial soaps, detergents, and waxes used for maintenance generate many irritating and sometimes toxic fumes and dusts, including formaldehyde, hydrocarbons, amines, ozone, and respirable particulates.
- Fluorescent lamps: The new popular sunlight simulating type as well as the standard fluorescent tubes emanate ultraviolet light. These lamps may provide energy for photochemical reactions among pollutants, thus forming the basis for indoor photochemical smog production. While the photon path length is quite short, affecting only a small amount of air around the fluorescent fixture, many ventilation systems circulate air around and over the light fixtures and even through vents built into them. This practice exposes a very large volume of air to photon bombardment.
- Parking garages, restaurants, and other nonoffice space use: Many large office developments also contain within the same building parking garages, access to transportation (such as buses and subways), restaurants, health clubs, and laundry and recreation facilities. These spaces may add substantial amounts of combustion byproducts, including carbon monoxide, oxides of nitrogen, carbon dioxide, and diesel exhaust to the indoor environment.
- Energy conservation methods: These usually involve reduction of fresh air ventilation rates. Reduction of the fresh air supply increases the rate of accumulation of pollutants by reducing the volume of air exhausted. The efficiency of standard air filters and their ability to control contaminants is reduced substantially as the velocity of the ventilation air is lowered. Many buildings now use a variable air volume system, which only introduces fresh air when cooling or heating is required. Occupants of buildings with this type of system often complain of stale, stuffy air, an indication of insufficient ventilation.

Today an estimated 25 percent of the U.S. workforce can be found in office buildings. Sealed, airconditioned buildings no longer provide occupants sanctuary from air pollutants and often do not even provide adequate thermal comfort. Yet new laws and standards now being considered to promote energy conservation, including ASHRAE series 100 energy conservation standards and the building energy performance standards proposed by DOE, are likely to cause severe discomfort, possibly leading to reduced productivity and even illness in the office workplace.

The 1980s are a transitionary period for architecture. The human health and comfort component of the building, in addition to energy conservation, new technology, and new materials, has begun to define a new design esthetic. Height, massing, and material use are the key architectural elements, combined with ingenuity and imagination, that will chart the course back to an architecture that serves rather than irritates. ☐

news from the NATIONAL RESEARCH COUNCIL

The National Research Council was organized by the National Academy of Sciences in 1916 in order to provide for a broader participation by American scientists and engineers in the work of the Academy. The Academy was chartered by the U.S. Congress in 1863 as a private organization with a responsibility for examining questions of science and technology at the request of the Federal Government. The National Academy of Engineering was organized in 1964 under the original NAS charter. The National Research Council now serves as the agent of both Academies in the conduct of studies and investigations in the public interest.

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Date: June 27, 1981
Contact: Rob Bier or Barbara Jorgenson,
(202) 389-6511

INDOOR POLLUTION: AN IMPORTANT, BUT UNCERTAIN PUBLIC HEALTH PROBLEM

FOR IMMEDIATE RELEASE

WASHINGTON - Carbon monoxide, formaldehyde, tobacco smoke, and radon, a radioactive gas. These are but a few of the hazardous substances that pollute the indoor air of homes, offices, and public building.

According to a new report by the National Research Council, some indoor pollutants regularly occur at levels above those permitted by law in the outdoor air. And with the recent emphasis on tighter seals in buildings to reduce energy costs, the situation may be worsening.

Nevertheless, the report declares, the scientific and technical knowledge needed to deal with the problem is sketchy and--in some cases--almost entirely lacking.

"Indoor exposure has been largely overlooked in research on the health effects of environmental pollutants, but it can constitute an important fraction of the total exposure to many pollutants," says the report, noting that many people spend as much as 80 to 90 percent of their days indoors. Not only do many pollutants have indoor sources, but the report points out that ventilation alone may not be enough to reduce adequately their levels--particularly when ventilation rates are cut back to save energy. The committee told the Environmental Protection Agency that "the present quality of the indoor environment and how this quality must change are matters of immediate and great concern."

(OVER)

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*Press copies of the summary sections of Indoor Pollutants are available from the Office of Information at the letterhead address. A very limited number of copies will be available to others early next week from the Committee on Indoor Pollutants, also at the letterhead address. Sale copies will be available from the National Academy Press in early September.

The report calls for a broad, nationally directed research effort, ranging from development of instruments suitable for monitoring indoor air to studies of the complex interrelationships between various pollutants, including how they move inside buildings and what ultimately happens to them. A key difficulty identified by the report is that of determining an individual's total pollutant exposure, given that indoor conditions vary greatly and that many of the same pollutants are encountered outdoors, in transit, and elsewhere. It calls for total exposure studies, acknowledging, "Such efforts are expensive."

Regarding solutions, the committee observed that even with good knowledge, the establishment of indoor-air quality standards "would not necessarily lead to rational or enforceable controls beyond ventilation controls for dilution." Instead, the committee recommended "reducing the number and strength of the sources [of indoor pollutants] by substitution of other materials." The committee also urged widespread public-education efforts.

The committee was asked by the EPA "to characterize the quality of the indoor environment, primarily with respect to airborne pollutants, and to determine the potential adverse health effects of indoor pollutants." It excluded industrial working environments from its consideration and defined "indoor" as referring to "homes, schools, public buildings, and similar spaces to which the public has access," such as bus terminals, sports arenas, and waiting rooms. The report focuses on seven classes of environmental factors "with indoor sources...identified as having substantial known or reasonably likely effects on human health," as follows:

Radon. Emitted indoors by soil, building materials, and groundwater, radon gas and its radioactive decay products often occur in concentrations an order of magnitude greater than outdoors, the report states. Although associated with lung cancer in uranium miners exposed at much higher levels, the potential health effects at levels found indoors cannot now be determined, leading the committee to call for such studies "as soon as possible."

Formaldehyde. Building materials such as plywood, particleboard, and urea-formaldehyde foam insulation are sources of this common pollutant, often emitting the gas over long periods of time. The lack of simple, reliable monitors for formaldehyde together with the influences of temperature and humidity on its detection have made it difficult to guage human exposure, the report states. A systematic study is needed of formaldehyde concentrations in a variety of situations. Recent animal studies showing cancer following long-term exposure to formaldehyde must be repeated to confirm the findings. For the present, the report recommends measures to reduce the amount of formaldehyde given off by products that use it.

Tobacco smoke. "Public policy should clearly articulate that involuntary exposure to tobacco smoke has adverse health effects and ought to be minimized or avoided," states the report, adding that smoking in public places should be restricted to well-ventilated zones. Research on the health effects of tobacco smoke and its constituents should continue.

Asbestos. Based on knowledge about the exposures necessary to cause asbestos-related diseases in workers, the committee said that "the very low concentrations reported in indoor spaces, such as schools, suggests insignificant health risk." It did voice concern over the possible risks to workers and building occupants when efforts are made to remove asbestos materials, and recommended containment measures.

Indoor combustion. A number of gases and particles can be concentrated indoors when fuel is burned, as with unvented gas cooking. The committee took particular note of carbon monoxide and nitrogen dioxide, saying "important population exposures...can occur indoors and may constitute a sufficient threat to the general public health to justify remedial action," namely direct venting or removal of the source. It noted that energy-conservation measures may cause heating equipment to be used at low levels that decrease its burning efficiency, thereby increasing emission of combustion products. The health effects of nitrogen dioxide and some other combustion products are unclear, however, as is human exposure to them.

Microorganisms and allergens. "It is possible that reduced ventilation and the increased use of untreated recirculating air could increase the concentrations of microorganisms," states the report. Although the committee found it reasonable to suppose that increased rates of infection and allergy could result, it said, "Little is known about the sources, concentrations, and survival rate of many aeropathogens in homes and other buildings."

Temperature and humidity. While not customarily thought of as agents of pollution, extremes of temperature and humidity can affect human health, particularly as they influence the activity and concentrations of gases and particles also present in the air, the report states. In particular, the report points out that excess humidity can increased the corrosive effect of absorbed gases, and may promote the growth of molds, algai, and fungi. "Thus, humidity control may become an important component of reduced-ventilation strategies," it says.

The report notes that consumer products are at least a potential source of many known or suspected carcinogens and toxic agents. However, their contributions to indoor pollution have been studied rarely, making assessment of potential health effects impossible. It also makes recommendations for investigating effects on human welfare and behavior and for studying the influence of building design and operation.

The Committee on Indoor Pollutants, a unit of the Board on Toxicologic and Environmental Health Hazards in the Research Council's Assembly of Life Sciences, was chaired by John D. Spengler, Harvard School of Public Health. Other members were: Michael D.Lebowitz (co-chairman), University of Arizona Medical Center; Ronald W. Hart, National Center for Toxicologic Research, Jefferson, Ark.; Craig D. Hollowell, University of California, Berkeley; Morton Lippman, New York University Medical Center; Demetrios J. Moschandreas, GEOMET Technologies, Inc., Gaithersburg, Md.; Jan A.J. Stolwijk, Yale University School of Medicine; David L. Swift, Johns Hopkins University School of Hygiene and Public Health; and James E. Woods, Jr., Iowa State University.

The staff officer was James A. Frazier.

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**AIR POLLUTION
CONTROL ASSOCIATION**

G. STEVE HART
President

May 14, 1982

Dear Congressman:

I am pleased to present herewith, for your consideration, a Position Statement of the Air Pollution Control Association (APCA) on the urgent subject of Indoor Air Quality.

This Position Statement, which was approved by the Executive Committee of our Board of Directors, was developed by APCA's Technical Committee on Indoor Air Quality. The committee is a body of professionals from throughout the United States whose expertise on indoor air quality has been gained from many years of involvement in that sector of air pollution control technology.

APCA is the only technical society that exclusively represents air pollution control professionals in the United States. Our membership of more than 8,200 in the United States and other countries is comprised of individuals in industry, science, government, and academia who are active professionally in all aspects of air pollution control.

Our officers have testified before committees of the United States Senate and the House of Representatives on the subject of air quality and, most recently, on amendments to the Clean Air Act.

With reauthorization of the Clean Air Act and amendments to the Act still a matter of debate today, the subject matter of this Position Statement on Indoor Air Quality is both appropriate and timely.

The Air Pollution Control Association urges you to give the Position Statement your serious consideration. If we can serve you further in this regard, please contact me or our Executive Vice President, W.G. Hamlin, at the headquarters office and phone number below.

Sincerely,

Steve Hart

G. Steve Hart
President

AIR POLLUTION
CONTROL ASSOCIATION

A POSITION STATEMENT ON
INDOOR AIR QUALITY

by the

Air Pollution Control Association

May 14, 1982

MARCH, 1982

AIR POLLUTION CONTROL ASSOCIATION
POSITION STATEMENT ON INDOOR AIR QUALITY

I. Introduction

The Air Pollution Control Association (APCA), through its Technical Committee on Indoor Air Quality, has assessed the available scientific information on the adverse effects on human health owing to exposure to pollutants indoors. (For the purpose of this statement, the indoor environment is broadly defined as any enclosed space -- e.g., individual residences, transportation terminals, and public buildings -- whose environmental quality is not controlled by specific regulations, as is the case for workplaces and ambient outdoor air. Also, the term "pollutant" is used in its generic sense and its usage here does not address any legal issues that might be suggested by definitions in existing statutes or regulations.)

II. Recommendations

Congress is herewith requested by the Air Pollution Control Association (APCA) to address the importance of indoor air quality by drafting specific amendments to the Clean Air Act to:

- Authorize and appropriate funds to ensure the continuation of research on the indoor air quality in such areas as technical monitoring and problem assessment to resolve competing policies.

- Authorize and appropriate funds to undertake a health effects assessment program.

- Authorize and appropriate funds to establish and support a national data base and information clearing house with appropriate scientific staff. This staff would advise state and local governments and the private sector engaged in research on indoor health effects, including building practices related to energy conservation and pollution control.

III. Justifications

APCA's position has been formulated on the basis of the following findings:

- The presently available scientific information shows that some pollutants known to be hazardous to human health are found indoors. Some of these are emitted by primary sources indoors, such as unvented combustion units.

- People in the United States spend a significant percentage of their time indoors. Some people spend 100% of their time indoors, making their indoor exposure time far greater than that of persons exposed in the workplace or in the ambient air outdoors.

- Susceptible human subpopulations at greatest health risk owing to exposure to hazardous indoor pollutants include pregnant women, both healthy and unhealthy newborn infants, children, and aged persons.

- In some instances, the indoor environment is the most significant source of human exposure to a pollutant, e.g., radon, asbestos, and tobacco smoke. Epidemiologic studies of health effects resulting from pollutant exposure most often do not include the exposures suffered by humans indoors, thus they do not determine the total exposure from all three environments: indoors, outdoors and workplace.

- Some energy conservation efforts and building practices (sealing openings and reducing air-exchange rates between indoors and outdoors) can adversely affect the quality of the indoor environment.

- During outdoor air pollution alerts, the indoor environment may not be a safe refuge or escape. The same pollutants found in the workplace or in the outdoor ambient air may also be found in the indoor environment; thus, exposure to pollution in all three environments may be additive.

- There is no national clearing house wherein collective scientific information or expertise about the non-workplace indoor environment is available for use by academic or private research organizations, medical or health care personnel, the general public, or state and local governments. Although several government agencies have information about some indoor pollutants no national data base exists.

Contact the Air Pollution Control Association
Headquarters for additional information.
P.O.Box 2861, Pittsburgh, PA 15230
Telephone: (412) 621-1090.

Environment International, Vol. 8, pp. 21-36, 1982
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0160-4210/82/070021-16$03.00/0
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INDOOR AIR POLLUTION

James L. Repace
Office of Policy Analysis,[†] Office of Air, Noise and Radiation, U.S. Environmental Protection Agency,
Washington, DC 20460, USA

As national trends accelerate towards the reduction of ventilation and infiltration rates in buildings, coupled with an increased use of synthetic chemicals in the indoor environment, a new phenomenon has arisen: the "sick building" syndrome. Traditional approaches to environmental health developed for the outdoor air, or for the industrial occupational setting, are inadequate to deal with this problem. It is argued that a comprehensive approach to the problem of indoor air pollution is necessary to protect public health.

Introduction

The Clean Air Act provides for the establishment of National Ambient Air Quality Standards (NAAQS) in order to protect public health from the effects of air pollution. The U.S. Environmental Protection Agency in its regulations, pursuant to the Act, has defined "ambient air" as "that portion of the atmosphere, external to buildings, to which the general public has access" (U.S. EPA, 1976; 1978). Consistent with this definition, state and local governments, who have the primary responsibility for the prevention and control of air pollution, have established a network of outdoor air quality monitoring stations that are located at fixed sites.

However, a number of studies have shown that fixed monitoring stations do not accurately reflect the pollutant exposure of the population in the outdoor environment (Repace *et al.*, 1980), while for many pollutants, indoor concentrations may be far in excess of the outdoor concentrations (NAS, 1981). When these indoor concentrations are weighted by the estimated 9-to-1 ratio for the time spent indoors relative to time spent outdoors by the U.S. urban population (NAS, 1981), the importance of indoor exposures for many air pollutants may exceed that of outdoor exposures.

For example, Fig. 1 shows a 24-h total respirable particle (RSP) exposure, using a piezoelectric microbalance to take time-resolved exposures as an individual moves from microenvironment to microenvironment (Repace *et al.*, 1980). On this day, the author spent 84% of his time indoors, 9% in transit, and 7% outdoors. His total integrated RSP exposure for the 24-h period is 1428 $\mu g/hm^3$. Contributions to the total exposure break down into 82.3% from indoor microenvironments, 9.8% from in transit microenvironments, and only 7.9% from outdoor microenvironments. Such results are indicative of a general trend.

Thus, to protect public health, a prime objective for public health agencies should be to limit the total human exposure to air pollution, rather than just the fraction which is incurred in the outdoor air. In this paper we will discuss the nature of the problem of indoor air pollution, limitations in the authority of established health agencies to control the problem, research needs, and some control options.

Background

It has been traditionally assumed that air pollution is primarily an outdoor phenomenon, and that buildings provide sanctuary from air pollutants. In fact, through ventilation and infiltration, air contaminants exterior to a building penetrate its interior to a varying extent and are persistent to a degree which depends upon ventilation/filtration system and the pollutant reactivity. For air exchange rates typical of non-energy-efficient buildings, indoor concentrations of relatively unreactive outdoor pollutants, such as CO, will lag the outdoor concentrations, but the daily average indoor and outdoor levels will be the same (Silberstein, 1979), especially in transit (Ott and Willits, 1981). For reactive outdoor

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[*] The views presented in this paper are those of the author.

[†] Reorganized as the Office of Policy and Evaluation.

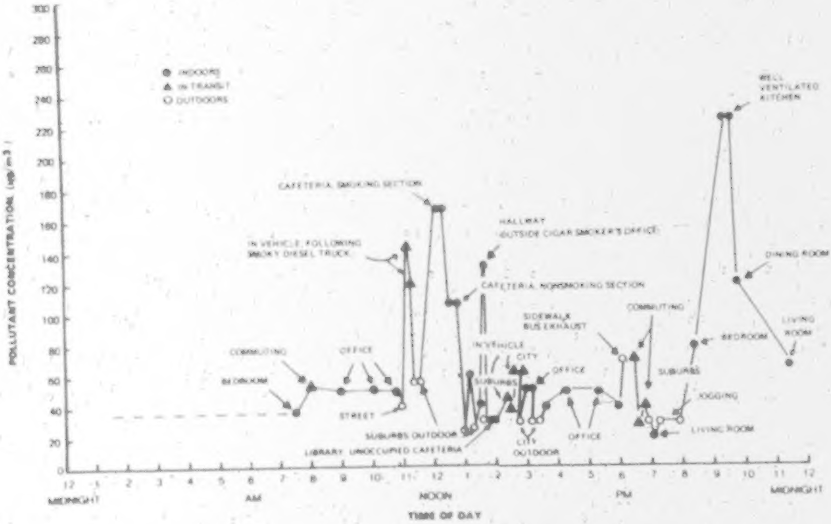

Fig. 1. 24-h indoor/outdoor RSP exposure of author, October 16, 1979. The 24-h average is 60 μg/m³ (Repace *et al.*, 1980).

pollutants, such as ozone, the indoor concentrations will lag the outdoor levels, but will average lower due to the presence of indoor sinks (Moschandreas and Morse, 1979).

However, in the presence of the persistent indoor sources, indoor concentrations of such pollutants will generally exceed the outdoor levels considerably. Moreover, there is a large class of pollutants, generated by the buildings themselves or by indoor human activities, which typically have no concentrations of physiological significance in the outdoor air. These include indoor air pollution from smoking, radioactive gases emanating from subsoil, emissions of formaldehyde from particle board, indoor pesticide use, human metabolic gases, and pathogenic organisms generated by coughing, sneezing, and flushing of toilets. Table 1 gives a partial list of indoor air pollutants in buildings by source and pollutant type.

A number of studies have indicated that indoor exposures to air pollutants can adversely affect human health and welfare (Repace and Lowrey, 1980; BNYAM, 1981; WHO, 1979; NAS, 1981). This problem is now assuming particular urgency as national energy conservation programs begin to focus on the large amounts of energy consumed by building ventilation systems in both residences and commercial buildings (Repace, 1981; Woods, 1979). Concerns about weatherization measures that can substantially reduce this outdoor air supply have arisen, because the replacement of more polluted indoor air by less polluted outdoor air constitutes the primary control measure for indoor air pollution; the slower the rate of this air exchange, the greater the level to which an indoor pollutant can rise. Such concerns prompted the U.S. Department of Energy (DOE) to call for the development of indoor air quality standards.

Indoor Pollutants of Current Concern

Radon and radon daughters

Radon gas and certain of its decay products are radioactive. Radon is emitted naturally from soil and mineral building materials. The level of radon and its decay products inside conventional buildings is often higher than the ambient level outdoor (Budnitz *et al.*, 1979), and inside poorly ventilated buildings these elements may accumulate to high levels due to the lack of diluting ventilation. It has been asserted (Budnitz *et al.*, 1979; Evans, *et al.*, 1981) that elevated radiation levels in conventional buildings and homes could increase the risk of lung cancer. The reduced ventilation and infiltration rates common to some new, airtight, energy-efficient residences could lead to a doubling of the average indoor radon levels, relative to the current building stock.

Table 1. Indoor air pollutants in buildings.[a]

Sources	Pollutant Types
Ambient air	SO_2, NO, NO_2, O_3, organics,
Motor vehicles	CO, particulates, CO, Pb,
Roofing tar	Polycyclic organics
Building construction materials	
Concrete, stone	Formaldehyde
Particle board, Plywood	Chlorinated hydrocarbons
Treated lumber	Formaldehyde, glass fibers
Insulation	Asbestos
Fire retardants	Organics
Adhesives	Mercury, organic solvents
Paint	
Building contents	
Heating and cooking combustion appliances	CO, NO, NO_2, formaldehyde, Particulates
Furnishings	Formaldehyde, other organics, mold and fungi
Well water	Radon
Natural gas	Radon
Copying machines	Ozone
Deodorants	Organics
Liquid marker blackboards	Organics
Carbonless carbon paper	PCBs
Air conditioning systems	Microbes, molds, fungi
Bathrooms, showers	Excess humidity
Flush toilets	Microbes, odors, disinfectants
"Air fresheners"	Formaldehyde, other organics
Human occupants	
Metabolic activity	CO, NH_3, odors, excess humidity
Coughing and sneezing	Microbes
Human activities	
Tobacco smoke	CO, NO_2, POM, nitrosamines Particulates, odors, irritants
Pest Removal	Pesticides
Cooking	Organics, particulates, excess humidity
Aerosol sprays	Fluorocarbons, vinyl chloride[b]
Cleaning products	NH_3, pine oil, chlorophenols
Hobbies and crafts	Organic solvents

[a] Adapted from a table originally given by Hollowell (1979).
[b] Banned by EPA in 1974 (U.S. EPA, 1975).

Evans *et al.* (1981) suggest that the radon-associated concentration in average U.S. residence is about 0.004 Working Levels (WL). The Working Level Month (WLM) is a measure of time-averaged radiation exposure from radon and radon daughters. An estimated 10%–20% of U.S. homes may exhibit levels more than twice as high; areas with anomalously high radon sources may be expected to show levels above 0.01 WL (U.S. EPA, 1979a). For a constant radon source strength, the gas concentration would increase roughly in inverse proportion to the airchange rate. Rates below 1 air change per hour (ach) are common in new housing. In Sweden, the national building code requires maximum infiltration rates of 0.6 ach and rates less than 0.2 ach are common (Anonymous, 1979; Woods, 1978). For comparison, the 1977 revisions (revision 5) of the 1973 Minimum Property Standards U.S. Department of Housing and Urban Development mandate infiltration rates for single family dwellings of less than 0.7 ach. A recent standard of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) suggests a rate of air change of 5 L/sec Room, or about 0.5 ach. Limited data currently exist on infiltration rates in U.S. homes. Based on a national sample of 200 homes, the U.S. Department of Energy estimates the range of infiltration rates in current housing stock is of the order of 0.75–1 ach, and between 0.4 and 0.7 ach in new housing, although some new housing is being built with exchange rates of the order of 0.1–0.2 ach (Fuller, 1981). According to Fuller (1981), a consensus seems to be developing in the U.S. building industry that an air infiltration rate of 0.5 ach can keep air pollutants below critical levels in a residence. In some homes, radon-associated lung-cancer risks can be high. USRPC summarized the available data (USRPC, 1980).

Figure 2 shows the radon concentrations in nCi/m^3 versus infiltration in a sampling of 12 energy-efficient (< 0.3 ach) homes in the United States, contrasted with the radon concentration in four homes whose infiltration rate is of the order of the national average (about 1 ach). Assuming a conversion factor of 1 $nCi/m^3 = 0.2532$ WLM/yr and a risk increase of lung cancer of 1×10^{-4} lung cancer deaths per WLM (Evans *et al.*, 1981), it can be seen that each 1 nCi/m^3 in radon/daughter exposure is associated with an estimated 0.25×10^{-4} increase in lung-cancer risk per year. To take an extreme case, 60 yr of residence at 75% occupancy in a home polluted at a 25 nCi/m^3 radon concentration (See Fig. 2) is associated with an estimated 2 per thousand absolute lung cancer risk, assuming a 20-yr latency period. For a lifetime exposure of 12 WLM and risk factor of 10^{-4} per WLM, Evans *et al.* (1981) estimate a maximum life time risk of 0.12%. To place this in perspective, such a risk to the U.S. population of lung cancer age, about 10^8 persons over age 35, would result in a maximum of about 120,000 lung cancer deaths in 60 yr, or about 1500/yr, assuming the average person spends 75% of his or her time at home.

Tobacco smoke

One out of three adults is a cigarette smoker. The typical cigarette smoker smokes 32 cigarettes/day, liberates 65,000 μg of respirable particulate per hour into the environment, and spends more than 90% of the day indoors. Thus, tobacco-smoke contaminated air is pandemic (Repace and Lowrey, 1980). Tobacco smoke is a proven human carcinogen and respiratory toxicant which causes a 77% excess cancer mortality in smokers, as well as a twofold excess of chronic obstructive pulmonary disease mortality (U.S. Surgeon General, 1980). Evidence is now accumulating that the diseases of

Table 2. Summary of indoor air pollution issues and options.

Some Indoor Air Pollutants of Current Concern	Indoor Air Pollution Issues Facing States	Summary of Clean Indoor Air Options
Tobacco smoke	Lack of recognition of indoor air pollution health effects	Research & development
Formaldehyde	Lack of diagnostic instruments and procedures for many pollutants	Measurement instruments and procedures
Radon daughters	Lack of trained personnel	Models for pollutant growth, equilibrium, and decay
Asbestos	Lack of viable control procedures	Health guidelines for maximum indoor concentrations
Unvented indoor combustion products from space heaters and gas appliances	Lack of appropriate indoor air quality standards	Epidemiological studies involving total multimedia exposure
Pesticides	Increasing frequency of sick buildings	Risk assessment
Airborne pathogens	Lack of consistency in regulation by various states creates problems for industry	Cost-effective control measures
Emissions from office copiers	Increased agitation for action by private groups	Regulatory tools for states
Carbon dioxide	Standards set by consensus groups impact industry adversely (litigation)	Product standards
Cleaning, deodorizing, and disinfecting products	Legislative initiatives	Building code provisions
Solvents, glues, and paints		Ventilation and air cleaning standards
		Indoor air quality-health standards

smoking may be visited upon the nonsmoker. Two recent studies of lung cancer in nonsmokers (see Repace, 1981) showed evidence that so-called passive or involuntary smoking (breathing of tobacco-smoke contaminated air by nonsmokers) more than doubles the nonsmoker's risk of lung cancer; two indoor epidemiological studies of morbidity, one of 400 adult nonsmokers who were chronically exposed to air pollution from tobacco smoke at work, the other of young children raised in households with smokers, found evidence of pulmonary impairment from passive smoking. A relationship has also been established between maternal smoking and sudden infant death syndrome (U.S. Surgeon General, 1980). These results may be placed into national perspective when it is considered that an estimated two-thirds of the children in the United States reside in households with smokers, and that nearly three-fourths of all U.S. employers allow unrestricted smoking in the workplace (Repace, 1981). Thus, for many nonsmokers, tobacco smoke exposure can be lifelong. Several studies have indicated that from one-half to three-fourths of nonsmoking adults experience symptomatic effects from ambient tobacco smoke exposure, including eye, nose, and throat irritation, headache and nausea, with much more severe effects reported in persons with cardiac or obstructive pulmonary disease. One study of 10,000 nonsmoking office workers indicated that work productivity was impaired in more than 50% of these employees as a result of co-workers' smoking (Repace, 1981). A 20% reduction in pulmonary flow has been produced in asthmatics from passive smoking (Dahms, 1981).

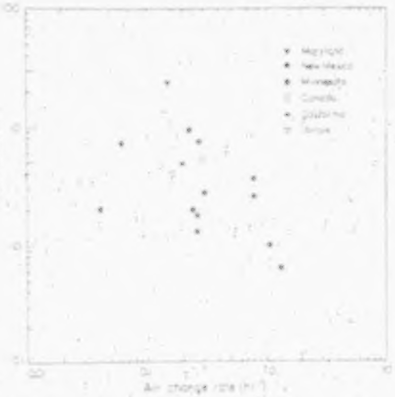

Fig. 2. Radon concentration vs ventilation in some U.S. homes (Hollowell, 1979). Under the Uranium Mill Tailings Control Act of 1978, EPA has set a maximum indoor air standard for radon decay products of 0.03 WL, with a recommended goal of 0.02 WL (roughly 3 nCi/m³) (U.S. EPA, 1982).

Studies of the levels of respirable particles (RSP) of less than 4 μm generated by smoking under natural conditions in indoor microenvironments showed a range of 90–1140 μg/m³, depending upon the smoker density and the effective ventilation. Levels of respirable particles in comparable indoor microenvironments in the absence of smoking ranged from 20 to 60 μg/m³; outdoor controls, which included measurements on busy commuter highways, showed values comparable to the indoor nonsmoking figures (Repace and Lowrey, 1980, 1982). This is illustrated in Fig. 3, in which the RSP levels commonly found in smoking microenvironments are superimposed upon the U.S. National Ambient Air Quality Standards (NAAQS) for total suspended particulate matter (TSP), in order to indicate whether a given observation is "high" or "low"; actual violations of the standard are not necessarily indicated. However, repeated exposures to such levels can lead to violations of the standard (Repace and Lowrey, 1980).

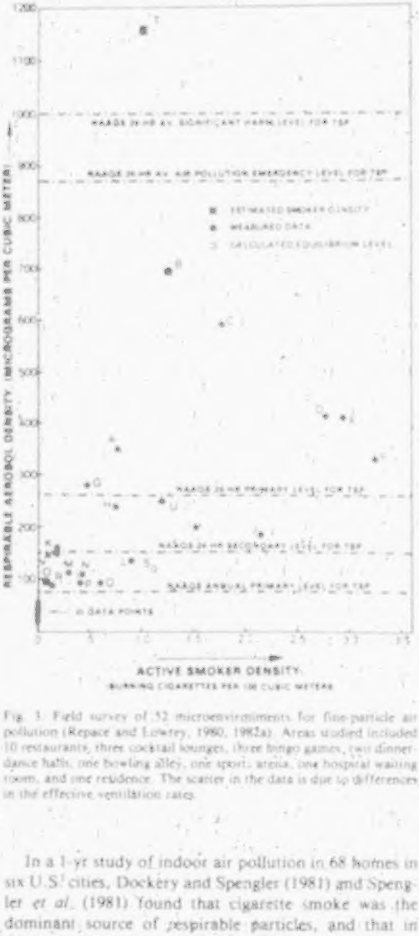

Fig. 3. Field survey of 32 microenvironments for fine-particle air pollution (Repace and Lowrey, 1980, 1982a). Areas studied included 10 restaurants, three cocktail lounges, three bingo games, two dinner-dance halls, one bowling alley, one sports arena, one hospital waiting room, and one residence. The scatter in the data is due to differences in the effective ventilation rates.

In a 1-yr study of indoor air pollution in 68 homes in six U.S. cities, Dockery and Spengler (1981) and Spengler *et al.* (1981) found that cigarette smoke was the dominant source of respirable particles, and that in tightly sealed homes, the RSP levels from smoking were more than double over the average. Nonsmokers exposed to indoor air pollution from tobacco smoke could inhale the equivalent of as much as 27 low-tar cigarettes per day; the researchers' estimates on the impact of passive smoking on nonsmokers based upon experimental and theoretical considerations support the findings of epidemiology. Figure 4 shows how the cigarette-equivalents inhaled varies as a function of the ventilation rate in an office building (Repace and Lowrey, 1980, 1982; Repace, 1981).

The indoor air pollution problems caused by smoking have generated two national constituencies: GASP (the Group Against Smokers' Pollution), a grassroots citizen's group, and ASH (Action on Smoking and Health), a legal organization. The American Lung Association has also begun to express concern. In 1979, 38 states introduced 116 bills regarding limitations of smoking in public areas. Seven were passed into law by seven states (U.S. DHHS, 1979). In 1980, of the 49 bills introduced under limitations, only one was passed into law by the state of California (U.S. DHHS, 1980). In 1979, the states passing these laws were California, Connecticut, Maryland, Montana, Nebraska, Oregon, and Rhode Island. Such laws are alternatives to nonsmokers' litigation (Repace, 1981). Many such laws require the establishment of nonsmoking sections in restaurants. Figure 5 demonstrates the efficacy of this approach. Minnesota is the only state presently to regulate smoking in the workplace as well as in restaurants, sports arenas, and other public and commercial buildings. Minnesota's law guarantees a smoke-free workplace to those nonsmokers who desire it. Enforcement of the law is reported to be working well. The U.S. Department of Health and Human Services has an internal policy that provides its own employees with a smoke-free workplace, upon request. In other federal agencies, this occurs only where there is unanimous consent of the workers. The Occupational Health and Safety Administration (OSHA) has no official policy regarding smoking. The U.S. Surgeon General, The World Health Organization, and the National Academy of Sciences have expressed concern about indoor air pollution due to tobacco smoke, and have urged greater efforts to prevent nonsmoker's exposures to tobacco combustion products (Repace, 1981; U.S. Surgeon General, 1982).

Emissions from unvented indoor combustion appliances

Another important source of indoor air pollution is from gas ranges and unvented space heating systems in

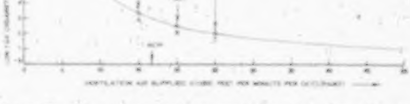

Fig. 4. The effects of ventilation on passive smoking in an office setting (Repace and Lowrey, 1982a).

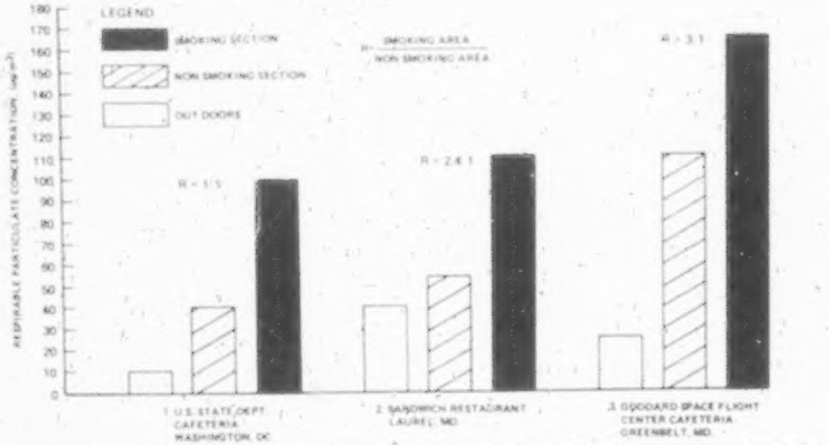

Fig. 5. Relative indoor/outdoor air pollution levels. Average sampling times were, respectively, 32, 20, and 8 min in each section for the three establishments (Repace and Lowrey, 1982a).

residential buildings. About 48% of U.S. homes use gas for cooking. There is also evidence that some urban apartment dwellers may be using unvented gas ranges for supplemental space heating. Laboratory studies have shown that gas stoves generate high emissions of such species as CO, NO_2, and also produce formaldehyde and respirable aerosol (Hollowell, 1979). Field studies have shown that levels of CO and NO_2 can exceed the levels of the short-term U.S. standards for CO, under certain conditions of ventilation in residential buildings; this is illustrated in Fig. 6, where the air change rates are given for a typical kitchen volume. The use of power ventilation reduces NO_2 levels considerably. ASHRAE now includes a 50 L/sec powered exhaust in its new indoor air standard (ASHRAE, 1981).

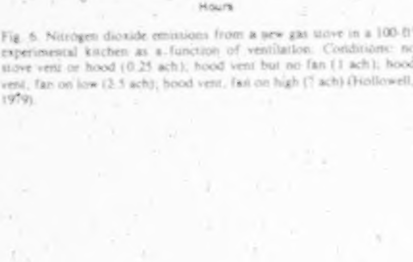

Fig. 6. Nitrogen dioxide emissions from a new gas stove in a 100-ft³ experimental kitchen as a function of ventilation. Conditions: no stove vent or hood (0.25 ach); hood vent but no fan (1 ach); hood vent, fan on low (2.5 ach); hood vent, fan on high (7 ach) (Hollowell, 1979).

Retrospective indoor epidemiological studies of respiratory illness in children both in the U.S. (Speizer *et al.*, 1980) and in the United Kingdom (Melia *et al.*, 1977) have reported higher rates of respiratory illness in young children raised in homes with gas stoves as opposed to electric stoves. The U.S. study, which was corrected for socioeconomic status and parental smoking habits, also reported significantly lower levels of forced expiratory volume (1-sec) and forced vital capacity for the gas-stove-home children. It has been hypothesized that these lower levels in the rate of functioning lung growth in young children could lead to an increased chance of rapid decline in pulmonary function in adult life. Other workers have reported instances of "chemical sensitivity" in some allergy patients exposed to the fumes of natural gas combustion (Randolph and Moss, 1980).

Other evidence from the Harvard Six-City study (NAS, 1981) clearly indicates that people cooking with gas without kitchen ventilation, or with only recirculating filters, will be exposed to indoor NO_2 concentrations greater than the outdoor ambient. Residents of homes with electric stoves or gas stoves vented to the outside will have indoor exposures lower than people with unvented gas stoves. These observations indicate that actual population exposures to NO_2 may not be adequately estimated by ambient outdoor measurements, posing serious implications for previous epidemiological studies of NO_2 and morbidity (Spengler and Dockery, 1979).

Emissions from unvented kerosene heaters can cause excessive levels of NO_2 and CO_2 indoors, and the possibility of excessive SO_2 emissions must be considered as well. A survey of 150 portable kerosene heater owners disclosed that 45% of the owners provided no ventilation when using the heaters, and that 20% used them to heat the entire house (Rodale, 1981). Most manufacturers recommend the use of extra ventilation.

Aeropathogens

Epidemiological studies have established that many infectious diseases are communicated by airborne transmission (Couch, 1981). Epidemics of influenza, measles, chicken pox (varicella), and rubella affect millions of people each year. Pulmonary tuberculosis (28,000 cases in 1980), smallpox, and Legionnaire's disease are also transmitted by airborne contamination. In addition, certain respiratory viruses such as epidemic coxsackie A21 and adenovirus types 4 and 7 are transmitted primarily by an airborne route.

Viruses are submicron in diameter, typical bacteria are between 1 and 2 μm in diameter, and mold spores range from 3 to 50 μm or more in size. Thus most of these biologically active aerosols are in the respirable range. One of the most important dispersion methods of contagious disease in man is via the expulsion of germ-laden droplets in sneezing, coughing, or even talking. These droplets are usually between 1 and 100 μm in diameter, and are expelled with considerable velocities. The larger droplets rapidly settle out on nearby objects and eventually evaporate, with the infectious residue being subject to atmospheric reentrainment by room traffic. The smaller droplets evaporate in mid-air, leaving the infectious microorganisms in suspension. A closely related mechanism is indirect liberation of dried secretions on handkerchiefs or bedding. Studies in hospital wards have shown that great numbers of bacteria are dispersed during bedmaking. The effect may be equally troublesome in domestic residences. Infective aerosols may also be formed by the flushing of toilets; respirable aerosols containing high concentrations of fecal bacteria may be formed in this way. Airborne molds and fungi may also contribute to allergic disease in the population (Green and Lane, 1964).

Although little is known about the typical source strength of such pathogens, the peak concentrations and halflives of these aerosols in buildings are probably inversely proportional to the ventilation rate of the building.

As an example of the impact of a disease which is commonly transmitted in buildings, consider epidemic rubella. Although commonly thought to be a childhood disease, in 1980 nearly 47% of the 3904 cases were in age groups ≥ 15 yr. (In 1979, there were nearly 12,000 cases; and in 1978 more than 18,000.) 70% of the cases were young adults (CDC, 1981). This was reflected by outbreaks in secondary schools, colleges, military installations, and places of employment, particularly hospitals. Because rubella can be teratogenic, its impact is most important in young adult females, 10%–20% of whom are susceptible (CDC, 1981). One such outbreak has been described among the employees in an office building of a New Jersey-based insurance company. During the summer of 1980, 10% of the susceptible employees were stricken during a 2-week period, with absenteeism more than doubling in the workforce (CDC, 1980). Although epidemic rubella is being brought under control by immunization, other airborne diseases, particularly influenza, remain rampant. The cumulative health and economic impact has yet to be estimated. Such epidemics are probably more likely to occur in poorly ventilated buildings due to the persistence of microorganisms in such airspace.

Formaldehyde

Formaldehyde is an irritating and probably carcinogenic gas (Sun, 1981), emitted from urea-formaldehyde foam insulation (UFFI), from resins used in plywood and particle board, and from gas stoves and cigarettes. According to news reports, families have complained to state and federal health agencies about UFFI, reporting symptoms such as dizziness, rashes, nose bleeds, and nausea (Sun, 1981). Eye irritation has been reported in indoor residential situations at concentrations as low as 24 μg/m³ or 0.02 μL/L (NAS, 1981). About 10%–20% of the population may be susceptible to formaldehyde vapors at low concentration, particularly at concentrations greater than 1.5 μL/L (NAS, 1981). Prior to its ban by the Consumer Product Safety Commission (CPSC), UFFI was banned in the States of Massachusetts and Connecticut, and also in Canada. California had imposed severe restrictions on the use of field-applied UFFI. According to news reports, there may be as many as 700 UFFI-related lawsuits currently pending, not counting a $2 billion class action filed on behalf of the 70,000 to 130,000 New York State residents who have UFFI in their homes (*New York Times*, 1982).

Mobile home residents were reported to have complained about strong concentrations of formaldehyde from wall coverings, furnishings, and carpets (Gold, 1980). One study, which involved measurements of formaldehyde emissions from particle board in residences, given typical quantities of particle board and typical infiltration rates, concluded that the use of this construction material in its present form (containing urea-formaldehyde glue) may result in higher indoor formaldehyde concentrations than permitted for continuous outdoor exposure in several European countries (Anderson *et al.*, 1975). A similar study conducted by Dally *et al.* (1981) reported that indoor residential exposure to formaldehyde may exceed levels of occupational exposure standards. Figure 7 shows relative indoor/outdoor formaldehyde levels for an energy-efficient house (Hollowell *et al.*, 1979). 1.5 ppm or μL/L

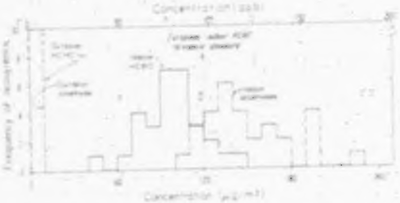

Fig. 7. Indoor/outdoor formaldehyde and aldehyde concentrations, Energy Research House, Carrol County, MD, March/April, 1979 (Hollowell, 1979).

(NAS, 1981). In Minnesota, the state chose to set a 600 µg/m³ standard. Wisconsin has also recently established a formaldehyde standard of 480 µg/m³ in mobile homes. By contrast, ASHRAE has adopted an indoor formaldehyde guideline of 120 µg/m³.

Pesticides

An estimated 84% of U.S. households use pesticides inside the house (U.S. EPA, NHPS, 1980), e.g., see Fig. 8. (The percentage of commercial buildings regularly using pesticides is not known, but may be presumed to be comparable.) Of those households, between 4 and 5% of the residents are estimated to have experienced acute toxic reactions after such use (U.S. EPA, 1980). Of households using pesticides, 17% used impregnated strips, 35% used mothballs, 90% used disinfectants, and 28% used pesticide-treated pet collars. All of these substances produce airborne concentrations of biocides. Few have been investigated for chronic toxicity. However, Dichlorvos DDVP, a constituent of some impregnated strips, is currently being investigated by EPA's Office of Pesticide Programs to determine the strength of the evidence for suspected, oncogenic, mutagenic, teratogenic, fetotoxic and neurotoxic effects (U.S. EPA, 1981).

In a study of commercial pesticide applications, treatments ranged from a low of 9% of households in EPA Region VIII to a high of 44% in Region IV. For homes treated with termiticides, the frequency of application ranged from a low of 2.5% in Region VII to a high of 55% in Region IV. In plenum-built housing or in buildings with subslab or intraslab heating and ventilation ducts, termite control chemicals have unintentionally been introduced into the living space, at times in such quantities so as to induce acute illness. Contamination of a home with pesticides or termiticides can be difficult to remove (Silberstein and Carroll, 1980). Although the extent of this problem is not known, the General Accounting Office has stated that the potential for such introduction is large, since about 40 million U.S. homes have warm air furnaces, and about 41 million are built on slabs. Chlordane, a proven animal car-

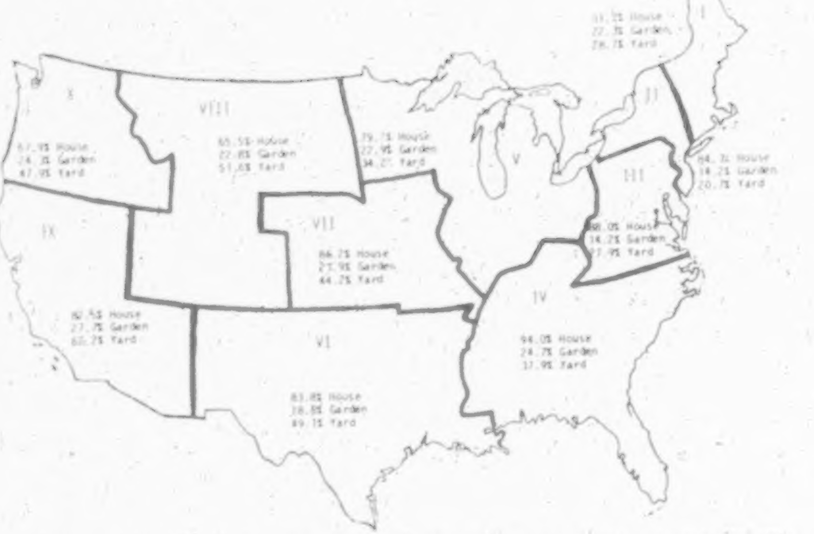
I
81.2% House
22.3% Garden
28.7% Yard
II
84.3% House
14.2% Garden
20.7% Yard
III
88.0% House
16.2% Garden
27.9% Yard
IV
94.0% House
24.7% Garden
37.9% Yard
V
79.7% House
27.9% Garden
34.2% Yard
VI
83.8% House
28.8% Garden
49.1% Yard
VII
86.2% House
21.9% Garden
44.2% Yard
VIII
65.5% House
22.8% Garden
51.6% Yard
IX
82.5% House
27.7% Garden
65.7% Yard
X
67.9% House
24.3% Garden
47.9% Yard

Fig. 8. Estimated percent of households using pesticides in the house, garden, or yard, divided into EPA regions (U.S. EPA, 1980).

cinogen for which EPA has cancelled virtually all above-ground uses, has been detected in the air of some termiticide-treated homes as long as 14 yr after application (Staats, 1980).

Building-related morbidity

An estimated 25% of the U.S. workforce can be found in offices (Rand, 1979). Within the past few years, the Center for Disease Control (CDC), the National Institute of Occupational Safety and Health (NIOSH), and many state health departments have been called upon with increasing frequency to investigate buildings in which a high percentage of workers report nonspecific symptoms (Kreiss, 1980). These buildings are usually office buildings, and standard industrial hygiene measurements generally fail to find a cause for the symptoms. Many of these cases are reported in modern, tight, energy-efficient office buildings, but problems are also reported in older buildings. CDC refers to such problems as "building associated epidemics," and has classified them according to probable cause: chemical, biological, allergic, "hysterical," or unknown. At times, the nonspecific symptoms persist for many months, and even years. There have been many reports from around the U.S. referring to such problems.

In addition to the evidence that buildings are not being ventilated adequately to accommodate the various sources of pollutants commonly found in buildings, studies are also showing that outside air dampers, which provide the minimal makeup air to replace that used up by human respiration, are being closed off by building owners and operators – in violation of building code provisions – in the interest of energy conservation (Repace and Lowrey, 1982; Repace, 1981; Kalika, 1970).

A random sample of the U.S. press provides anecdotal evidence of building-related morbidity. In Fort Worth, TX, the Tax Assessor's Office was forced to close down in May 1981 because "15 to 18 employees called in sick, and those who stayed on the job complained of 'burning lungs,' symptoms related to fumes that have permeated the building since it was opened in February 1981." The Assessor could not predict when the tax office would reopen (*Dallas Morning News*, 1981). In May 1978, The University of Massachusetts at Amherst was forced to shut down temporarily a three-tower, 17-story building complex after faculty and staff complained of dizziness, fatigue, nausea, and menstrual irregularities. Inconclusive studies carried out by campus authorities and OSHA prompted the faculty union to hire their own investigators, but no findings have yet been released (*New York Times*, 1980). A rash of complaints about "sinus congestion, chest pains, sore throats, headaches and general depression" began soon after the Ottawa County, MI, Human Services building opened in November 1978. The absentee rate among the 60 social services employees jumped to 64% from the normal 10% by the spring quarter of 1979, and by October 1979 it "remained high." At that time, the employees hired an attorney and submitted a petition to be moved to another building. Attempts by the county to remedy the poor air quality in the building included installing negative ion generators "to get the proper ion balance back." However, the generators had "no effect." In November 1979, the State authorities were considering ordering the building closed down. Tests of the air quality by county and State officials were inconclusive (*Muskegon Chronicle*, 1979). As of November 1981, despite the transfer from the building of several of the worst-affected employees, and the direct expenditure of more than $50,000 – exclusive of investigative efforts by federal, state, and local authorities – complaints continue at the rate of several per month. The Orchard Park Elementary School in Carmel, IN, has been closed since December 1979, when 60% of the school's 52 teachers complained of headaches, nausea, and eye and nasal irritation. Nearly a year later, state health officials were still unable to identify the cause (*Indianapolis Star*, 1980).

A series of hearings by the State of California on "Buildings That Make You Sick" reported, among other problems, on the San Francisco Department of Social Services Building in which more than 50% of the workers suffered from irritation of the eyes, nose, and throat, and others reported more serious problems (*Los Angeles Times*, 1980). The NIOSH investigator complained that "even though we had conclusively demonstrated a health problem among the workers in the building, there existed no standards against which we could adequately measure their exposure." As a result, a summary of the NIOSH report issued by the building management to the employees stated that "the [NIOSH] report received . . . indicates that the quality of the air within the building appears to be acceptable according to the standards of the Public Health Service" (California State Hearing, 1980).

A pilot study of the occupational health of 960 clerical workers in Cleveland and Boston "from every industry and job category" disclosed that 70% of the workers complained that fresh air in their offices was "inadequate or nonexistent"; the study also reported that job-related stress was significantly correlated with poor indoor air quality (Gregory, 1981).

According to press reports The Office of Environmental Disease Control at the Maryland State Health Department reports one to two indoor air complaints per day, mostly related to office buildings (Minkoff, 1981). New York City's Department of Environmental Protection receives an average of 4 complaints per week concerning indoor air quality, although its activities in this area are not publicized. According to the director of its Bureau of Science and Technology, "Federal leadership is required lest we misdirect our efforts in an attempt to be responsive to growing public demand" (Ferrand and Moriates, 1981).

Schmidt and Hollowell (1980), in an investigation of air contaminants in a California office building in which the occupants complained about poor air quality, found that no contaminant exceeded individual Threshold Limit Values established by OSHA; however, many more contaminants were found indoors than outdoors, and the indoor levels were higher. In such cases (Fig. 9), the burden of exogenous chemical substances with which individuals must cope may be far higher than normal and may exceed the body's ability to detoxify.

The phenomenon of exceedance of a critical total body burden is known to be an important factor in triggering or maintaining environmentally related disease (Rea, 1979a; 1979b). Susceptible individuals among inhabitants of buildings with poor indoor air quality may experience an exceedance of this critical burden and as a result develop what has been termed "environmental maladaptation syndrome," a spectrum of noninfectious disease processes, which affect smooth muscle, mucous membranes, and collagen in the respiratory, gastrointestinal, genitourinary, and vascular systems, producing a broad variety of symptoms which defy traditional diagnostic techniques, and which may be mistaken for hypochondriasis (Rea, 1979a, 1979b).

There is therefore a need to approach indoor air quality as an ecological science. At present, however, there is little detailed knowledge of the import of the contaminant levels to which building inhabitants are exposed (Rand, 1979).

Limitations on federal authority to regulate indoor air pollution

The General Accounting Office has reviewed the responsibilities of federal agencies involved in various aspects of the problem of indoor air pollution (GAO, 1980):

> a. EPA is the lead agency for air pollution, with its responsibility derived from the Clean Air Act. EPA's interpretation of this act, however, limits its responsibility to pollution occurring in the outside air.
>
> b. OSHA is responsible for safeguarding the worker's health in the workplace. This includes setting and enforcing indoor air exposure standards for certain known pollutants. These standards are set so as to protect the majority of workers.
>
> c. DOE, by Congressional mandate, establishes energy conservation programs for residences and new buildings. While DOE is concerned with the environmental impact that these programs have on indoor air quality, its primary interest and responsibility is energy conservation and not indoor air quality.
>
> d. CPSC evaluates the safety and health effects of consumer products including those which may emit indoor pollutants such as formaldehyde and asbestos. CPSC can, if warranted, force a product to be withdrawn from the market, provided it is sufficiently demonstrated that the product is hazardous. CPSC can also set standards for products and has responsibility for providing information on product safety to consumers.
>
> e. HUD establishes building standards for certain government properties and material standards for mobile home construction. HUD is therefore concerned with the impact of various pollutants, such as radon and formaldehyde, on the quality of indoor air.

GAO has concluded that there is a lack of clearly assigned responsibility which has impeded Federal actions to study indoor air pollution and to develop adequate control measures, and has recommended to the Congress that the Clean Air Act be amended to provide EPA with the authority and responsibility for the quality of air in the nonworkplace. We shall examine this recommendation.

EPA's interpretation of its mandate under the Clean Air Act derives from its definition of ambient air as "that portion of the atmosphere, external to buildings, to which the general public has access." This in turn derives from an assumption that the air internal to buildings can be no more polluted than the outdoor ambient. Thus, in principle, if the phrase "external to buildings" is deleted from the definition of ambient air, under a rule-revision process, EPA's authority could thereby be extended to encompass all of the air to which the general public has access. However, this has been viewed by some as contrary to the legislative history of the Act. Nevertheless, there are some established precedents for EPA's indirect involvement in the regulation of indoor air quality. The Clean Air Act provides EPA the authority to control or limit the manufacture and use of hazardous chemical substances such as benzene, vinyl chloride, mercury, beryllium, and asbestos, regardless of where they are used. Currently a vastly enlarged group of hazardous air pollutants is being considered for addition to this list, with carcinogens being accorded a high priority. Many of the 39 chemicals currently undergoing a Hazardous Air Pollutant Assessment may be present in high concentrations indoors.

For controlling the adverse effects of sources of hazardous pollutants, Section 112 of the Clean Air Act provides the basic EPA regulatory authority. Section 112 provides for the control of pollutants from airborne sources that may cause an increase in serious irreversible or incapacitating illness. The Act requires listing of pollutants that are considered hazardous, establishing emission limitations and in some cases, mandating work practices that provide an ample margin of safety to protect health. NESHAPS (National Emission Standards for Hazardous Pollutants) are the principal regulatory authorization for control of airborne carcinogens. In addition, under Section 122 of the Clean Air Act the Administrator is given authority to regulate radioactive pollutants, polycyclic organic matter, or other pollutants which may reasonably be anticipated to endanger public health. Under this authority, EPA has engaged in researching the problem of radon in the indoor environment.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (as amended through 1978) EPA has promulgated regulations (40 CFR 162.16) which control pesticides intended for residential application, including houses, mobile homes, recreational vehicles, and other indoor areas.

With regard to certain air pollutants, particularly the ones for which ambient air quality standards have been established, EPA has viewed its authority as limited to the outdoor ambient, while for certain hazardous substances, EPA has viewed its authority as extending to the indoor environment (e.g., vinyl chloride).

The Public Health Service Act, Public Law 92-623, Title III, "General Authority Respecting Research, Evaluations, and Demonstrations in Health Statistics, Health Services, and Health Care Technology" provides that "The Secretary [of the Department of Health & Human Services] and the National Academy of Sciences shall, jointly and in cooperation with the Administrator of the Environmental Protection Agency [and other specified agencies], conduct, with funds appropriated under Section 308(i)(2) an ongoing study of the present and projected future health costs of pollution and other environmental conditions resulting from human activity (including human activity in any place in the indoor or outdoor environment, including places of employment and residence)" [Section 304(d)(1)]. The law further provides for the identification of the pollutants, the diseases caused by such pollutants, the sources of the pollutants, an assessment of the extent of the harm of the pollution, and a quantification of both the present and projected future health costs of this pollution as well as the reduction in health costs which would result from its reduction.

A persistent problem which has arisen in the investigation of many "sick buildings" is that of appropriate indoor air quality standards. A number of such standards, the Threshold Limit Values (TLVs), have been utilized by OSHA for industrial workplaces. These consensus standards are designed such that "no employee will suffer material impairment of health or functional capacity" (OSHA, 1970). However, the TLVs, unlike the outdoor air quality standards set by the U.S. Environmental Protection Agency under the Clean Air Act, are not designed to protect the general public to "within an adequate margin of safety," but rather to protect "nearly all" workers without adverse effect (ACGIH, 1978). It is explicitly recognized that because of the wide variation in individual susceptibility, a minority of workers may be affected by discomfort at levels below the TLVs, or even by aggravation of a preexisting condition or by development of an occupational illness (ACGIH, 1978). Thus, standards developed for the industrial workplace, as Coye (California, 1980), Taylor (1980), and Oslager (1980) have suggested, may not be appropriate for indoor air quality standards designed to protect the general public, and in particular the white-collar workforce which may contain many more pollution-sensitive individuals than the blue-collar workforce (Gregory, 1981).

For example, the OSHA 8-h standard for carbon monoxide is 50 μL/L, while the EPA 8-h standard is 9 μL/L. Further, the OSHA 8-h standard for "inert or nuisance dust" is 15,000 $\mu g/m^3$. Exposure at this level implies a 5000 $\mu g/m^3$ 24-hr average and a 4800 $\mu g/m^3$ annual average. By contrast, the EPA 24-h average primary standard is 260 $\mu g/m^3$ and the annual primary or health-based standard is 75 $\mu g/m^3$. Such differences in standards may account for reports in which office workers have become ill because of indoor air pollution, yet air sampling has failed to find any single compound in concentrations above the OSHA standards (Taylor, 1980; Oslager, 1980; California State Hearing, 1980; Schmidt and Hollowell, 1980). The strict application of industrial-based standards for the protection of office workers in polluted buildings may result in the exclusion

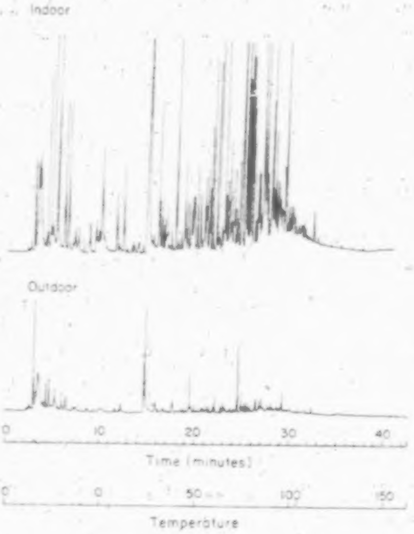

Fig. 9. Gas-chromatographic analysis comparison of indoor and outdoor air at a Lawrence Berkeley Laboratory office site. Indoor and outdoor samples were taken simultaneously (Schmidt and Hollowell, 1980).

of sensitive individuals from employment. Problems involving indoor air pollution are particularly salient in this respect (Barad, 1979; Repace, 1981). Therefore, if indoor air quality standards are promulgated, nonindustrial workplaces such as offices, public buildings, schools, hospitals, places of recreation, and residences, might best be covered by standards appropriate for the protection of sensitive groups.

Actions by Governmental Agencies and Private Groups Which Affect Indoor Air Quality

The U.S. Department of Energy (DOE) proposed two programs that will have an impact on indoor air quality through energy conservation in buildings: the Residential Energy Conservation Service program (RCS) (U.S. DOE, 1979b) and the Energy Performance Standards for New Buildings (BEPS) (U.S. DOE, 1979c). The potential for indoor air quality impacts under RCS lay mainly in retrofit caulking and weatherstripping efforts carried out by homeowners. DOE projected a 25% average reduction in infiltration rates for those homes which participated in the program. Such reductions could be expected to result in a like increase in indoor pollution equilibrium concentrations in such homes in the absence of mitigating measures. DOE, at the behest of the Congress, has proposed to expand RCS to small commercial buildings (U.S. DOE, 1980). The BEPS program, which now has been terminated, impacted both residential and commercial buildings, by setting maximum Design Energy Budgets for these structures.

Design ventilation and infiltration rates are set by ASHRAE. In 1973, these rates were codified under ASHRAE Standard 62-73, "Standards for Natural and Mechanical Ventilation," which set forth minimum ventilation rates, based on the need to limit the buildup of CO_2 in the indoor air from human metabolic processes and to control industrial air pollution in factories and recommended higher ventilation rates in certain premises, based on the necessity to control odor, mainly from tobacco smoke. These standards did not recognize that there were nonmetabolic, nonindustrial sources of indoor air pollution (ASHRAE, 1973). In 1975, ASHRAE promulgated Standard 90-75, "Energy Conservation in New Buildings" (ASHRAE, 1975). ASHRAE 90-75 eliminated the "recommended" category of ASHRAE 62-73, leaving only the minimum metabolic rates for the limitation of CO_2 (5 cfm or 2.5 L/sec of makeup air per occupant). Such low rates however, may lead to heavily polluted buildings in the presence of strong indoor sources of air contaminants (NAS, 1981; Anderson *et al.*, 1975; Repace and Lowrey, 1980).

In August 1981, ASHRAE announced a new standard, 62-1981, "Ventilation for Acceptable Indoor Air Quality" (ASHRAE, 1981). The objective of the standard is to "provide healthful and comfortable indoor environments by using materials and methods that optimize efficiency of energy utilization." Acceptable indoor air quality is defined as "air in which there are not known contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction." ASHRAE standard 62-1981 operates to control indoor air pollution by offering alternative procedures to the design engineer: either ventilation rate tables to be used in the absence of "unusual" indoor air contaminants or an "indoor air quality standard" method. The latter method implies that the design engineer is aware of all "unusual" sources of air pollution in the proposed building, that the engineer knows the generation rates of the pollutant from all sources, and that an acceptable indoor air pollution transport model for each pollutant exists so that a maximum or an equilibrium concentration for the pollutant can be calculated and compared with an indoor air quality standard for the contaminant in the space, where such a standard exists. In the absence of a health-based indoor air quality standard appropriate for the general public, OSHA standards or "best available control technology" is recommended. However, few indoor air standards appropriate for the general public are available at the present time.

The ventilation rate tables of ASHRAE 62-1981 set minimum ventilation rates (2.5 L/sec per occupant) based on an implicit CO_2 standard of 2500 ppm (2.5 mL/L), and would apply in nonsmoking buildings; higher ventilation rates are designed to be used in buildings in which smoking is permitted, because "tobacco smoke is one of the most difficult contaminants to control at the source" (ASHRAE, 1981).

The rates set by the standard for tobacco-smoke contaminanted environments have been criticized as inadequate (Cain, 1981; Leaderer, 1981; Repace, 1981). Yet they are as much as five times higher than for equivalent indoor environments where smoking is not permitted. Tobacco smoke is also one of the most difficult contaminants to control economically by ventilation.

Approaches to the Formation of Indoor Air Pollution Policy

Issues

The basic issue is that indoor air pollution is known to produce a wide variety of health effects, but there is little explicit authority to deal with this problem. As a result, resources cannot be brought to bear the needed research and control effort. Federal, state and local health authorities are often called upon to deal with suspected cases of indoor air pollution; however, they are frequently ill-equipped to deal with problems involving diagnosis, measurement, and control of indoor pollutants. Furthermore, there is no national mechanism appropriate to control building materials, work practices, or ventilation rates to achieve good indoor air quality. Nor are there indoor air quality guidelines or standards suitable for the residential and nonindustrial work environments which typically contain members of sensitive groups. However, these health authorities are being called upon with increasing frequency to investigate "sick buildings" in which a high percentage of the occupants report the nonspecific symptoms of indoor air pollution. Traditional industrial hygiene and occupational medicine techniques often prove unsatisfactory in coping with the problem. In efforts to control indoor air pollution, some states have passed indoor air quality standards, and others have banned products. Such a sporadic approach may lead to fragmented regulation, widespread confusion, and insufficient protection for building inhabitants.

Announced federal policies

The U.S. General Accounting Office (GAO) has called for the establishment of a federal task force, led by EPA, to identify and coordinate federal and private sector research activities relating to indoor air pollution, to compile data on indoor air pollution problems which will serve as a data base for states to use when they have indoor air-pollution problems, to inform the public on how to cope with indoor air pollution, and finally to plan research and development efforts needed to deal with the indoor air pollution problem (GAO, 1980). Some initial efforts to comply with GAO's approach have been made. An Inventory of Current Indoor Air Quality-Related Research has been compiled (Meyer and Hartley, 1981) and the proceedings of a Workshop on Indoor Air Quality Research Needs (Ross and Berg, 1981) has been published by an Ad-Hoc Interagency Research Group on Indoor Air Quality. Its members included representatives from the Departments of Energy, Housing & Urban Development, Health and Human Services, Defense, Labor, Commerce, and Interior, as well as the Consumer Product Safety Commission and the Environmental Protection Agency. Most workshop participants expressed their feeling that indoor air pollution will become a major focus of new environment-related research efforts in the 1980's.

However, a major federal role in dealing with indoor air pollution is by no means assured. In an era of declining research budgets, the lack of legislative authority to regulate indoor air quality may seriously retard the development of a national indoor air pollution research program which has been announced. A GAO inquiry has revealed that although federal money managers may agree that indoor air pollution presents a problem, they are reluctant to devote resources to such research (GAO, 1980). Indeed, the lack of legislative authority to address the problem of indoor air pollution continues to hinder EPA management, resulting in a view of indoor air pollution research as peripheral to its charter under the Clean Air Act and occurring at the expense of mandated programs.

A comprehensive approach

As recommended by the GAO, the Clean Air Act could be revised to control indoor air pollution in much the same way as outdoor air pollution is now controlled. States could be given the primary authority to regulate indoor air quality. Enforcement of regulations would be complaint-oriented. The federal government's role might include research and development of monitoring instruments and determination of standard procedures for the measurement of various pollutants in indoor air, as well as the establishment of suitable ventilation rate standards, building material standards, consumer product emission standards, work practices, training of state personnel in indoor air pollution control, and appropriate indoor air quality standards or guidelines.

The Air Pollution Control Association (APCA) has also urged (APCA, 1982) the U.S. Congress to amend the Clean Air Act to authorize the appropriation of indoor air quality research funds, to initiate an indoor air pollution health effects assessment program, and to establish a national indoor air data base and information clearinghouse.

The federal role might also involve reviewing and approving state programs for the control of indoor air quality, which would promote uniformity and consistency among the states according to the principle of equal protection under the law. An appropriate federal agency would have primary responsibility for conducting indoor air research and developing standards and guidelines for the states' use in regulating indoor air quality. How such an approach might be implemented is discussed in detail below.

Research & development needs. Federally sponsored research and development should be oriented toward determining diagnostic instruments and procedures for the precise and accurate measurement of pollutants at ambient concentrations; development of reliable models for indoor air pollution transport and indoor/outdoor air pollution relationships; establishment of health-based indoor air quality standards or guidelines; measurement of the emission rates of pollutants from typical indoor sources; performing epidemiological studies of occupants' health in both "sick" and normal buildings; development of personal monitors and computerized dataloggers for total exposure studies (Wallace and Ott, 1982); risk assessment of indoor/outdoor air pollutants; evaluation of real or putative control measures for indoor air pollution, i.e., source control ventilation, air–air heat exchangers, electrostatic precipitators, high-efficiency fabric filters, charcoal filters, negative ion generators, etc.

Indoor air pollution regulatory options. Under the Clean Air Act, the term "Ambient Air" could be defined as "that portion of the atmosphere, both internal and external to buildings, to which the general public has access." The term "general public" could be defined so as to include white-collar workers in nonindustrial settings, particularly in commercial office buildings. Regulations might cover indoor air in such places as private residences, commercial buildings, institutional buildings, and recreational facilities, as well as commercial passenger aircraft, trains, and buses. Regulatory measures would generally focus upon controlling the sources and concentrations of pollutants rather than attempting to control human behavior.

Regulatory mechanisms used to control indoor air pollution could require that some air quality standard, action level, or goal be set as a guide for the appropriate control technique. Ambient indoor air quality standards would not necessarily be set and enforced in the indoor environment in the same way as in the outdoor environment. Rather, implicit indoor air quality standards could be used as guides against which the adequacy of emissions standards or building codes would be judged. In some cases, however, explicit legal standards might be necessary, particularly pertaining to minimum ventilation rates in commercial buildings.

There are a number of alternative approaches to the setting of indoor air quality standards:

a. Criteria air pollutants: In a minor modification of the Clean Air Act, simply adopt the National Ambient Air Quality Standards as standards for the indoor environment, possibly with modifications to account for synergisms with other indoor air pollutants.

b. Hazardous air pollutants: Similarly, standards for all pollutants which are held to be hazardous under Section 112 or Section 122 of the Clean Air Act would also explicitly apply to the indoor air environment.

c. Indoor air pollutants: The act could call for the establishment of a new category of indoor air pollutants not limited to the "criteria" or hazardous air pollutant list. The maximum permissible indoor level for current "criteria" or hazardous pollutants also would not necessarily be the same as in the outdoor air to allow for potential synergisms or mitigating factors. Risk analysis could be performed to determine those worth regulating, and also the amount of control necessary.

Using the indoor ambient "action level" concept, the main thrust of new regulations in the indoor air pollutant area might thus focus on technology-based standards and emissions controls, which would be implemented through building code changes and new product standards. Listed below are three examples of how new product standards and building codes might be employed to prevent the buildup of excessive indoor air pollution.

New product standards. In order to limit indoor formaldehyde concentrations to safe levels, indoor pollutant concentrations beyond "a given" action level for formaldehyde might require the control of emissions from particle board containing urea-formaldehyde resin.

Meyer (Meyer, 1980a, 1980b) has given an instructive example: A typical one-family residence might have approximately 186 m^2 of particle board; a mobile home might contain as much as 743 m^2 corresponding to about 4.5 ton of particle board. If 0.1% of this resin is not fully cured, this could amount to 0.23 kg of free formaldehyde. The correlation between the level of formaldehyde vapor in the building and the quantity of latent formaldehyde in the particle board can be predicted, given the quality of the particle board, the total amount of board installed, and the air infiltration or ventilation rate. In Japan, a product standard issued in 1977 prescribed a maximum release of 5 mg of formaldehyde per 100 g of resin. This keeps the air concentration in a typical Japanese residence below 120 $\mu g/m^3$ (Japan, 1970, 1977). According to Sundin (1982) Swedish resin manufacturers have successfully reduced the free formaldehyde content in the resin by as much as a factor of 8.

Building code standards. For a pollutant such as radon gas, in which the source is the subsoil of the building, and the route of entry is seepage through cracks in the foundation, radon infiltration into new residential buildings could be effectively limited by building-code requirements specifying the installation of vapor barriers.

Control of indoor air quality through automatic ventilation procedures. For gas stove emissions in residences, and for carbon dioxide or tobacco smoke concentrations in large office buildings with automated centralized heating, ventilating, and air conditioning (HVAC) control systems, automatic sensors may serve to control pollutant concentrations to within acceptable limits. For example, Fig. 6 shows that the NO_2 levels exceed certain presumed short-term air quality standards at the infiltration rates currently assumed to be typical of U.S. homes with the windows closed. Thermal sensors could be required to be installed in all gas stoves (electric stoves might also be included to control particulates from cooking) to activate a ventilating fan mounted over the stove; building codes would be correspondingly modified to require ventilation fans in all new dwellings. As Fig. 6 shows, the spot ventilation rates generated by stove hood exhaust fans can be adequate to control the concentrations of NO_2 from gas stoves.

With respect to indoor air pollution in large office buildings, it is possible that a few pollutants, acting as surrogates for other, less common pollutants could be monitored by sensors mounted in central ducts located on each floor of the building. When the levels of the pollutants exceeded certain present standards, ventilation rates could be automatically increased, and larger amounts of outside makeup air could be inducted into the system. Currently, ASHRAE requires a minimum of 5 cfm per occupant in many buildings, based on limiting

CO_2 levels to 2500 ppm; however, there are persistent reports that such low rates of induction of outside air are creating indoor air pollution problems. A sensor set to limit CO_2 to, say, 500 ppm might remedy some of these.

Acknowledgements—The author would like to thank P. Stolpman for his encouragement and support in producing this work, and is indebted to H. Ross for his critical reading of the manuscript, and to A. Moghissi for his editorial suggestions.

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INDOOR RADON MEASUREMENTS WITH TRACK ETCH® DETECTORS

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Presented at the:

27th Annual Meeting of the Health Physics Society
Las Vegas, Nevada
June 27 - July 1, 1982

ABSTRACT

Track Etch® detectors have been used to measure over 40,000 time-averaged radon exposure rates in U.S., Swedish and Canadian homes. Results show that in some areas of the U.S. the exposure rate exceeds 20 pCi/l in as many as 15% of the homes surveyed. These levels may lead to a significantly increased lung cancer risk. The exposure rates in a particular geographic locale range over several orders of magnitude and are distributed log-normally.

Sources of radon in homes with high concentrations were usually the soil and rocks under the houses and associated well water. Building construction materials and general water supplies were normally found not to be significant radon sources. Tightly sealed, energy efficient homes were also found to have increased radon levels.

The radon measurements were made using both filtered cup and bare detector configurations. The detecting element in each is a plastic nuclear track recorder which undergoes permanent radiation damage when struck by an alpha particle. The damage track is made visible in a microscope by chemical etching. The filtered cup is used for highly accurate measurements while the bare detector is intended for large-scale screening surveys. Because both types of detectors are small and totally passive, they were found to be very convenient for making measurements in occupied homes and buildings. The etched detectors also provide a permanent, retrievable exposure record.

The detectors were extensively calibrated in several internationally recognized radon irradiation facilities, including the DOE's Environmental Measurements Laboratory and the U.S. Bureau of Mines. Radon concentrations ranging from 3.5 to 584 pCi/l and exposure times ranging from 3 to 120 days were used in these calibrations. Background distribution data show that the lower detection limits are 0.07 and 0.16 (pCi/l)-months for the bare and filtered cup configurations respectively.

INDOOR RADON MEASUREMENTS WITH TRACK ETCH® DETECTORS

INTRODUCTION

Radon progeny have long been known to cause lung cancer where present in high concentrations in underground mines (Se76). Recently there has been increasing concern over the lung cancer risk to large populations exposed to supposedly lower concentrations indoors (St80). The source of indoor radon is radium in underlying soil and rocks, and in building materials. Radon can enter the home with water and natural gas through cracks or openings in walls or floors in contact with the soil. Whether or not there are abnormally high radon sources, indoor radon concentrations could increase as a result of energy conservation programs (Ho79).

Indoor radon surveys, with the one notable exception of 10,000 homes in Canada (McG80), have been limited to only a few homes at a time. Large scale surveys have been impractical due to the cost and inconvenience of existing radon measuring instrumentation. Moreover, most surveys have been made with grab samplers, although it is known that the indoor radon concentration can vary greatly with time (Ar79).

The Track Etch® technique (Al72) has been developed and calibrated for use in large indoor surveys (Fl80; Al81a; Al81b). The totally passive Track Etch monitors are inexpensive and convenient to use. Because they are rugged and insensitive to environmental factors, they are also reliable. Their integrating character enables them to measure time-averaged radon concentrations, thereby eliminating errors that can result from temporal fluctuations in concentration.

This technique consists of counting the radiation damage tracks produced by alpha particles in certain plastic materials. The tracks are enlarged by an etching process, and the track density on the plastic detector is measured by microscopic examination. Two configurations of the Track Etch detector have been found to be especially useful for both indoor and outdoor radon monitoring. They are a bare detector, which is sensitive to the total alpha activity of the atmosphere (radon and radon daughters), and a detector in a cup covered by a filter, which measures radon only. Both configurations have been employed in the data to be described. The detector response to radon exposure has been determined in a series of 40 calibration tests in four different standard radon chambers in the U.S., Sweden and Denmark (Al81b).

This paper summarizes the numerous indoor radon measurements made in the U.S., Canada and Sweden over the past few years by means of Track Etch monitors. Over 40,000 indoor measurements have been made to date, and the results show that in some instances the indoor radon concentrations are surprisingly high. This suggests that more indoor measurements are needed to fully understand the extent of radon as a public health problem.

RADIOLOGICAL HAZARD FROM RADON

Alpha-radioactive radon gas emanates everywhere from the earth as a result of the naturally occurring uranium and radium in the earth's crust. Radon decays in several steps to a stable isotope of lead. The intermediate, non-gaseous radon daughters are themselves alpha emitters and constitute the primary radiological health hazard to man.

In an indoor atmosphere one finds a mixture of radon and its daughters. The daughters may or may not be attached to other particles suspended in the air. When this mixture is inhaled the radon daughters may attach themselves [illegible] terior walls of the lung and bronchial tubes where they can d[illegible] lly very high doses of high-LET alpha radiation. (Fig. 1)

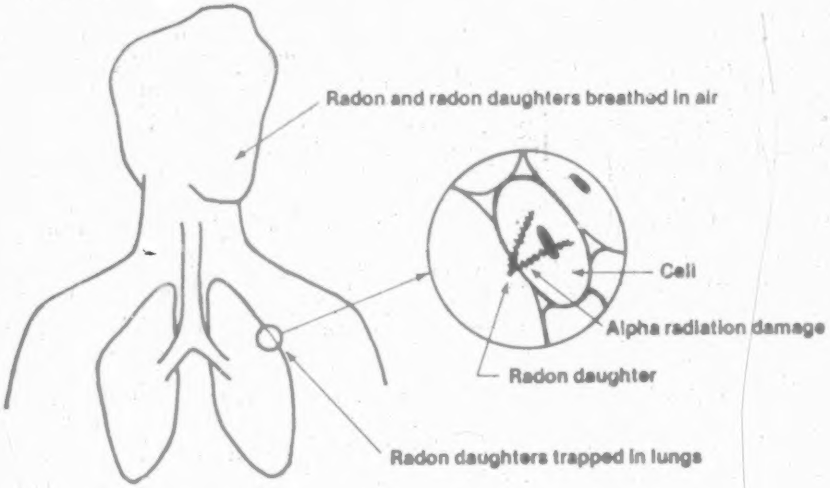
Radon and radon daughters breathed in air
Cell
Alpha radiation damage
Radon daughter
Radon daughters trapped in lungs

Fig. 1. Effects of Radon and Radon Daughters on Humans

SOURCES OF RADON INDOORS

The principle source of radon indoors is the radium which results from uranium in the underlying soil and rocks. Figure 2 shows how radon enters a dwelling through cracks or openings in walls or floors in contact with the soil. Radon can also enter a building by way of the water and natural gas supplies. Certain building materials are sufficiently high in radium content so as to constitute significant radon sources in some situations. Tightening homes to reduce the air change rate for energy conservation purposes increases the radon concentration. Specially constructed dwellings, such as earthen homes and solar heated structures with rock heat storage, are also frequently high in radon due to the radon sources from the additional earth and rock that are integral parts of such buildings. The data that we and others have collected indicate that the major source is the soil and rocks beneath the home. (Sa81, Ab81, Hi81).

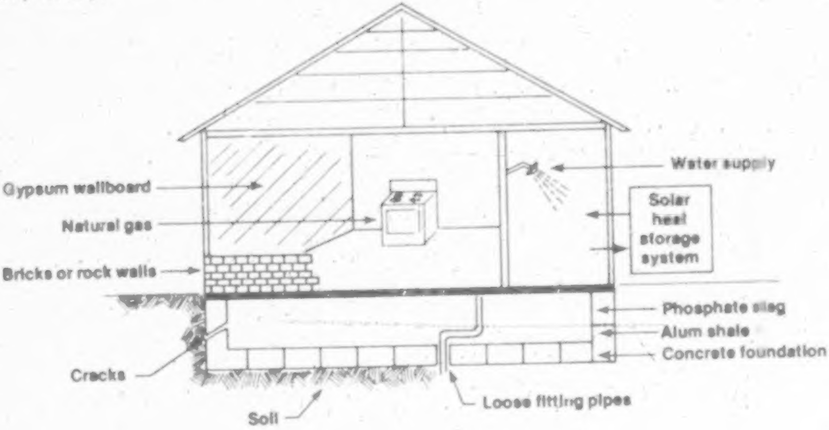

Fig. 2. Sources of Radon in Homes

Radon surveys done to date have usually involved a relatively small number of homes and have frequently been done using grab sampling methods which give instantaneous readings even though it is well recognized that radon concentrations vary considerably with time at a given location in a dwelling. Passive, integrating Track Etch detectors provide a convenient means of making long-term, time-averaged measurements in large numbers of homes, thereby eliminating the effects of temporal variations.

TRACK ETCH DETECTORS

Track Etch radon monitors are based upon plastic nuclear track detectors that are sensitive only to alpha radiation. When alpha particles penetrate the track detector, they produce radiation damage tracks that are retained for very long periods of time. In a chemical etching treatment these tracks are made visible and are counted microscopically. The reading of the detector is in tracks per unit area and is proportional to radon exposure. (Fig. 3)

A variety of deployment configurations have been developed to suit particular needs in terms of measurement precision and convenience of deployment and handling.

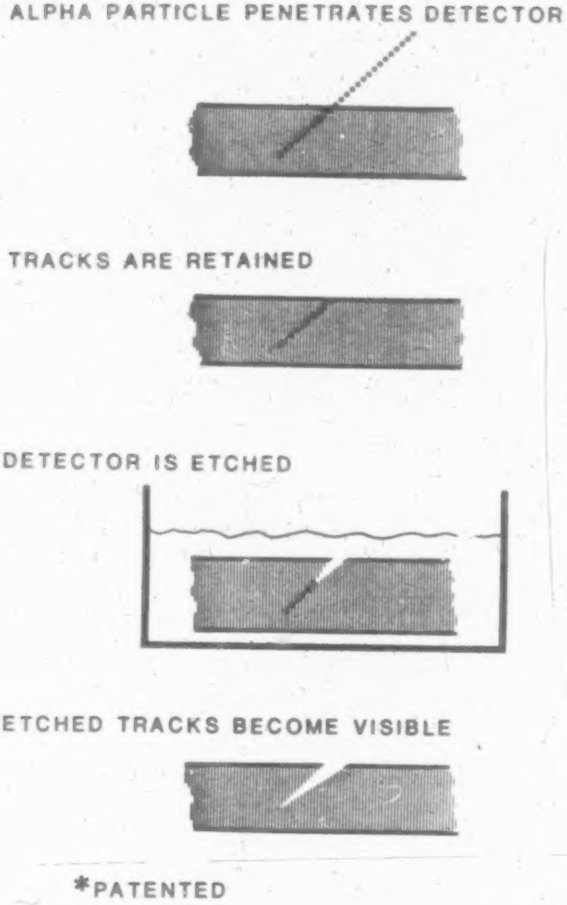
ALPHA PARTICLE PENETRATES DETECTOR
TRACKS ARE RETAINED
DETECTOR IS ETCHED
ETCHED TRACKS BECOME VISIBLE
*PATENTED

Fig. 3. How Track Etch Works

One recent development is the small filter cup radon detector shown in Fig. 4. It measures about one inch high and one inch in diameter. It responds only to radon in the atmosphere being monitored and is therefore suitable for precise indoor measurements. It can also be used for personnel monitoring for radon and can be equipped with a clip for that purpose.

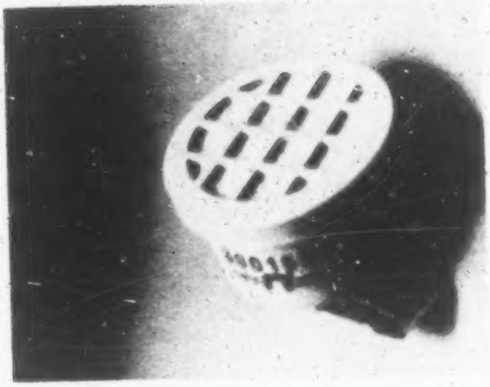

Fig. 4. Type SF Radon Detector

For large scale screening surveys the bare card configuration shown in Fig. 5 was developed. It is convenient to deploy through the mail and is easy for a homeowner to use by simply mounting on a wall. The accuracy of individual measurements made with this device is not as good as that which can be achieved with the filter cup detector. However, it is quite suitable for statistical surveys in which the intention is to find the mean value and range of radon concentration and to isolate the dwellings having the highest levels in a large sample.

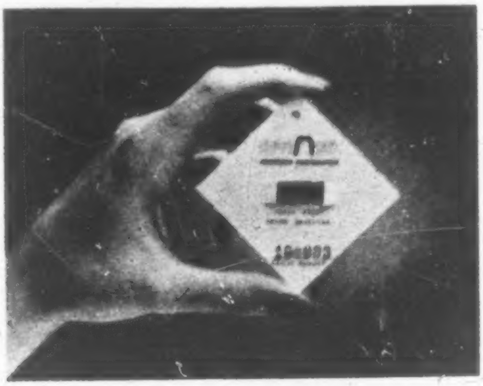

Fig. 5. Type B Radon Detector

All the various Track Etch detector configurations have been extensively calibrated at several internationally recognized calibration facilities including radon chambers at the Dept. of Energy's Environmental Measurements Laboratory, the U.S. Bureau of Mines, the Australian Radiation Laboratory and others. Calibrations have been performed at radon concentrations ranging from 3.5 to 584 pCi/l and exposure times from 3 to 120 days.

RESULTS OF RADON SURVEYS WITH TRACK ETCH DETECTORS

Table 1 presents a representative sample of some of the radon surveys done with Track Etch detectors. The surveys are classified according to location. The number of measurements made in these surveys varied from several hundred in the U.S. and Canadian surveys to thousands in Sweden. Usually two or three detectors were used in each dwelling. Detectors were generally placed in a basement, when present, and in one or two living areas.

Table 1

INDOOR TRACK ETCH RESULTS
(Expressed in Average Radon Concentration)

Location-Season	Radon Concentration pCi/l		Percent Greater Than 20 pCi/l
	Mean	Range	
N. Calif. winter-summer	0.5	0.1- 2.1	0
Houston fall-winter	0.4	0.1- 2.7	0
No. East U.S. summer	0.3	0.1- 3.6	0
E. Penna. winter-spring	2.4	0.1- 91	15
Maine fall-spring	1.1	0.1- 133	3
Canada winter-spring(1)	3.6	0.1- 34	4
Sweden winter-summer(1)	2.1	0.4- 22	4
Sweden spring-summer(1)	4.1	0.2- 106	4
Sweden fall-winter(1)	8.1	0.2- 520	14
Sweden winter (1)	10.0	0.5- 466	15
Sweden winter-spring(1)	9.5	0.5- 1140	12

(1) Selected Homes

The homes surveyed in Maine and eastern Pennsylvania had concentrations up to about 100 pCi/l, while some dwellings in Sweden had levels as high as 1000 pCi/l. Furthermore, the homes studied in these surveys were not selected as energy efficient and so represent ordinary homes.

Our results and those of others show that local geology is usually the overriding factor in determining radon levels in dwellings. This was a surprising result in the Swedish surveys which constitute thousands of measurements. At the beginning of the Swedish program a few years ago, preliminary measurements showed a number of dwellings with high radon levels. It was suspected that this was due to the rather high radium content of many Swedish building materials. As the surveys proceeded and data accumulated it became evident that high radon concentrations were more highly correlated with the radium content of the earth on which the dwelling was built as opposed to the radium content of the building materials. This conclusion has continued to be supported as more and more data are accumulated. Therefore, despite the banning of many building materials that are high in radioactivity, there is still cause for concern that structures may have high radon levels when built in areas where the natural geology is high in uranium and radium.

What is particularly noteworthy in this tabulation is the percentage of homes in some areas with radon concentrations in excess of 20 pCi/l. The remainder of this discussion will be used to explore the implications of this in terms of public health hazard.

RADON AS A PUBLIC HEALTH PROBLEM

As mentioned previously, the radiological hazard to man arises from radon daughters which result from the radon in the atmosphere. Equation 1 relates radon daughter exposure rates expressed in Working Level to radon concentration expressed in pCi/l by means of the quantity known as Working Level Ratio.

$$WL = \frac{WLR \times Rn}{100} \qquad (1)$$

WL = Working Level
WLR = Working Level Ratio
Rn = Radon Concentration in pCi/l

Stranden (St79; St81) and others have found that typical indoor environments can be characterized by a Working Level Ratio of about 0.5 on the average and range from about .3 - .7. Equation 1 shows, then, that a 20 pCi/l radon concentration corresponds to 0.10 Working Level.

Let us now examine this observation in light of the EPA's risk estimate shown in Table 2. This is a reproduction of a table given by the EPA in the Federal Register (EPA80).

Table 2

ESTIMATED RISK OF FATAL LUNG CANCER DUE TO
RADON DECAY PRODUCTS (1)
(for 0.01 Working Level and Lifetime Exposure 75 percent of the Time)

	Estimated Risk	
	Relative	Absolute
Percent of the exposed who will die of lung cancer caused by the exposure(2)	1	0.5

(1) Estimated lifetime risk of fatal cancer caused by the indicated rate of radiation exposure over an average lifetime (70.7 years).

(2) The percentage for higher or lower radiation levels changes in proportion, except for very high levels. Exposure over less than 70.7 years gives smaller risks; however, the expected effect of an exposure depends on the recipients age at the time, so the risk is not strictly proportional to the exposure time.

Table 2 shows, according to the relative risk model, that 1% of individuals exposed to 0.01 Working Level for an average life span of 70.7 years will die of lung cancer caused by the radiation exposure. This estimate assumes an exposure 75% of the time. Proportioning this to 0.1 Working Level, we find that 10% of the individuals so exposed over a lifetime will die of lung cancer from the exposure.

Let's now combine this risk estimate with the limited data that we have on radon levels in dwellings. Recall that in some areas as many as 15% of the homes surveyed had levels greater than 20 pCi/l; some surveys had 3 or 4%, some had none. Based on these observations, we might reasonably guess that a few percent of the U.S. population spend 75% of their time at or above 20 pCi/l. To simplify the calculation of possible radon related deaths, let's assume that 1 - 5% of the whole 200 million U.S. population (i.e. 2 - 10 million individuals) occupy dwellings at exactly 20 pCi/l. Of this 2 - 10 million, 10% will die of radon-related lung cancer using the EPA risk estimate. That is, between 200,000 and 1 million potential radon-related lung cancer deaths may occur in the current U.S. population. This estimate is not inconsistent with that of Berk and others (Be79). Even reducing these numbers by a factor of ten to account for uncertainties in the quantities used in the computation still leads to many thousands of potential lung cancer deaths. These rough calculations seem to indicate that there is sufficient justification for suspecting that radon may be a significant national health problem. It unquestionably is a health problem in some U.S. dwellings. Certainly the limited surveys done thus far indicate a need for further assessment of the extensiveness of the radon problem.

CONCLUSIONS

Our experience has shown that passive integrating detectors are well suited for indoor radon measurements. Data from these surveys and those of others show that the primary radon source is soil and rock beneath a dwelling.

High radon concentrations have been observed in many buildings. Although it has not been discussed in this presentation, radon levels in buildings may frequently be reduced by increased ventilation using mechanical devices such as air-to-air heat exchangers.

In view of the results of the limited radon surveys done thus far, it seems reasonable to consider radon to be a significant potential public health problem. More radon measurements are needed in order to assess more fully the extensiveness of the indoor radon problem.

ACKNOWLEDGEMENTS

This paper could not have been written without the kind cooperation of the following organizations, under whose sponsorship some of the work was done: U.S. Environmental Protection Agency, Statens Provningsanstalt, General Electric Company and Pennsylvania Power and Light Company.

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minimum value during that cycle (Fig. 1C). The cycles of V_{O_2} were closely followed by oscillations in T_{th}, with the peaks in V_{O_2} slightly preceding the peaks in T_{th} (Fig. 1C). We assume that the cycles in V_{O_2} and T_{th} coincide with cycles of activity in the thoracic flight muscles. The T_{ab} values sometimes showed similar, but smaller oscillations which lagged behind those of the thorax. Our experiments usually lasted 2 to 3 hours, and during this interval the beetles were almost completely motionless and T_{th} was continuously elevated. We did not determine the maximum duration of the homeothermic response of *Megasoma*.

As long as T_b remains constant, heat production is necessarily equal to heat loss. Heat loss is proportional to the difference between T_b and T_a (ΔT); in the case of endothermic insects T_b refers to T_{th}. A mammal with a T_b of 37°C at a T_a of 23°C should have the same heat loss as a *Megasoma* of the same mass with a T_b of 27°C at a T_a of 13°C. (This parity requires that the mammal and beetle have similar thermal conductances.) It is instructive to compare the V_{O_2} (which is proportional to heat production) of a homeothermic *Megasoma* with that of placental mammals of similar mass experiencing the same ΔT (Fig. 2). For comparative purposes we have selected two small rodents whose metabolic rates were measured with an open-flow respirometry system smiliar to that used for *Megasoma* (*8*). The rodents, a kangaroo mouse (*Microdipodops pallidus*) and a pocket mouse (*Perognathus californicus*) have lower V_{O_2} than *Megasoma* of the same mass when ΔT is greater than 5° to 7°C (that is, at T_a below the thermal neutral zone of the mammals). Below thermoneutrality, the mass-specific thermal conductances of the mammals did not change with T_a, whereas the mass-specific thermal conductances of the beetles decreased linearly with T_a. For example, the conductance of an 11-g beetle was 0.42 ml of O_2 per gram per hour per degree Celsius at a T_a of 26°C but was only 0.30 ml of O_2 per gram per hour per degree Celsius at a T_a of 8°C. The decrease was apparently caused by a decline in T_{ab} from 27.1° to 15.5°C while T_{th} remained constant. Consequently, heat loss from the abdomen decreased with decreasing T_a.

The dearth of information on the natural history of *Megasoma elephas* makes ecological interpretation of the homeothermic metabolic response problematic. We assume that when T_b is regulated above T_a during terrestrial activity, the pattern of T_b regulation is the same as the pattern we observed in the laboratory at T_a below 20° to 22°C; that is, that variation in heat production rather than variation in heat loss to the abdomen is the primary mechanism of control of T_b. *Megasoma* is certainly capable of supporting normal activity levels by regulating a high T_b at T_a below 20° to 22°C (T_a values as low as 15°C have been recorded on Barro Colorado Island), but we do not know whether the beetles could fuel the metabolic increase required, should T_a remain low for more than a few hours.

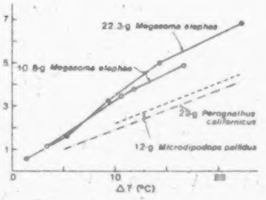

Fig. 2. A comparison of the relation of mass-specific V_{O_2} to ΔT in scarab beetles and heteromyid rodents of similar size. The curves for rodents are the regressions of their euthermic energy metabolism below the thermal neutral zone (*8*). The points for the beetles are the means of 16 or more measurements taken while T_{th} was constant at a given T_a.

To our knowledge, among insects, a homeothermic metabolic response to decreases in T_a in the absence of locomotor activity has only been reported in worker honey bees (*9*) and in incubating queen bumble bees (*10*). The homeothermic responses of the beetles reported here were not as fine-tuned as those of birds and mammals. In the beetles, T_b declined to about 20° to 22°C before there was any regulation. Thereafter, their metabolic response to a decrease in T_a was qualitatively similar to that of birds and mammals. However, instead of maintaining T_b constant, there was an oscillation over a range of 3° to 4°C with the frequency but not the amplitude of the oscillations increasing with ΔT. The beetles appear to have a definite set point below which they "defend" T_b. The greater the ΔT, the more rapid the heat loss and the more rapid the oscillations in V_{O_2} and T_b.

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5 February 1982; revised 13 April 1982

Indoor Airborne Asbestos Pollution: From the Ceiling and the Floor

Abstract. *Electron microscopic measurements of the concentrations of airborne asbestos were carried out inside and outside an office building having ceilings sprayed with a crocidolite-containing material and floors covered with vinyl-chrysotile tiles. Under normal conditions in this building, constructed 10 years ago, the two asbestos-containing materials released fibers into the air. This is the first measurement of elevated (up to 170 nanograms per cubic meter) concentrations of indoor airborne asbestos associated with the weathering of asbestos floor tiles during their service life. Asbestos flooring is used in a large number of buildings and represents the third largest use of asbestos fibers in the United States and in Europe, ranking after roofing and asbestos-cement pipe.*

The potential hazard arising from exposure to airborne asbestos inside buildings sprayed with asbestos-containing materials is currently the subject of much concern. The Environmental Protection Agency has undertaken a large-scale program to control friable asbestos-containing materials in school buildings (*1*). The Conseil Supérieur d'Hygiène Publique de France has recommended controlling the concentrations of airborne asbestos inside buildings sprayed with asbestos (*2*). Since 1975, analytical facilities for the measurement

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of asbestos, with an analytical transmission electron microscope (ATEM), have been available in our laboratory (*3*). Thus far, 493 air samples from 122 buildings have been analyzed. In December 1980, we were asked to monitor the airborne asbestos within a building, the ceilings of which had been sprayed in 1970. In this building, an additional and unexpected emission source of airborne asbestos was discovered: the asbestos floor tiles.

The building, located 20 km south of Paris, was occupied by an engineering company that was marketing optimized electronic computer systems. The 300 workers were all white-collar employees, working under clean conditions inside offices, graphic studios, and workshops where electronic machines were being tested. The six floors (900 m^2 each) showed similar architectural configurations with peripheral workrooms and a central core occupied by elevators, stairs, corridors, and blind storerooms. Measurements of the indoor airborne asbestos pollution were requested because of the presence on the corridors' ceilings of a suspicious, friable, blue material that had been sprayed on. This material was located in an open plenum where it could be eroded by the circulating return air. Another possible cause of deterioration was the fact that electricians sometimes operated on the plenum electric lines.

We took five bulk samples by penetrating the total depth of the sprayed material with large-mouth containers in five randomly predetermined locations. Analysis of their fiber content with the polarized light microscope (PLM) revealed that they were almost pure crocidolite (*4, 5*). Neither man-made mineral fibers nor chrysotile were detected. Further analysis with the ATEM (Fig. 1, a and A) did not reveal the presence of fine chrysotile fibers unresolved by the PLM.

Air was sampled simultaneously at four indoor sites and on the roof where fresh air entered the air-conditioning system. Air-sampling units had been operating for five consecutive working days but only during building activity periods. Air sampling during activity periods is of primary importance, since it has been observed that the concentrations of indoor airborne asbestos measured during periods of active use are much higher than those measured during nonuse periods (*3*). It is believed that human activity not only contributes to the degradation of materials but is also a factor in the fragmentation and secondary dispersal of settled dust (*6*).

Airborne asbestos measured outside the building showed the usual features encountered in the urban area of Paris and its suburbs. Only chrysotile was encountered, with a mass concentration of 0.1 ng/m^3. Earlier measurements of 249 air samples from 35 locations in this area revealed a homogeneous background of ambient airborne chrysotile. Concentrations were in the range of 0.1 to 9 ng/m^3 (median, 0.4 ng/m^3), with 95 percent below 3 ng/m^3. Commercial amphibole-type asbestos fibers have not as yet been detected in significant quantities in urban air samples.

Inside the building, both crocidolite and chrysotile were present in the air samples (Fig. 1B). Concentrations were 0.2, 0.5, 0.9, and 33 ng/m^3 for crocidolite and 8, 21, 25, and 170 ng/m^3 for chrysotile at sites 1, 2, 3, and 4, respectively. Sites 1, 2, and 3 were corridors; site 4 was a workshop including part of a corridor. The concentrations rose from site 1 to site 4 in the same order for crocidolite as for chrysotile.

Obviously, the airborne crocidolite fibers within the building were released from the crocidolite-containing material sprayed on the ceilings. The concentrations can be compared with those measured earlier inside a series of 36 buildings sprayed with a material containing amphibole-type asbestos, generally amosite or crocidolite (Fig. 2). Fifty percent of such buildings showed detectable concentrations of amphibole-type asbestos fibers in the air; only 22 percent of the buildings showed concentrations in excess of 33 ng/m^3, which was the maximum concentration of amphibole-type asbestos fibers in the air of the building reported here. Bearing in mind these reference data and because the architec-

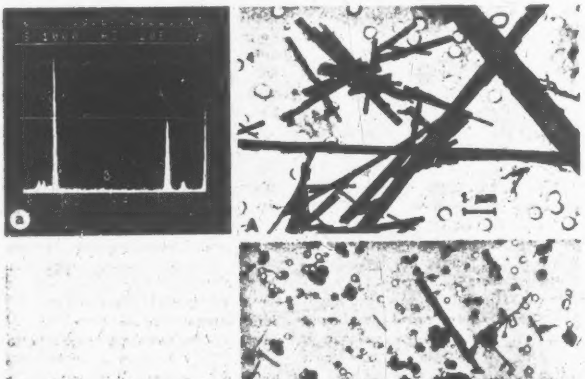

Fig. 1. Characterization with the analytical transmission electron microscope [a conventional transmission electron microscope fitted with an x-ray energy-dispersive spectrometer (EDS)] of asbestos fibers isolated from the material sprayed on the ceilings (a and A), an air sample (B), and a vinyl floor tile (c and C). The EDS spectra of individual fibers are typical of crocidolite (a) and chrysotile (c). Fibers of both asbestos types were encountered in the air samples (B).

tural configuration of the building was not favorable, we recommended that some corrective action be taken (*7*) to prevent further crocidolite fibers from becoming airborne.

The elevated concentrations of indoor airborne chrysotile were very surprising in view of the absence of detectable chrysotile in the sprayed material. A further warning sign was the shortness of the airborne chrysotile fibers; no fiber longer than 3 μm was encountered on the membrane filters. Further investigations were undertaken to discover the origin of such fibers. Inquiries revealed no use of asbestos products by the workers. The air-conditioning system was carefully investigated; no asbestos-containing material was discovered. Water used to dampen the conditioned air was analyzed with the ATEM; no chrysotile fiber was detected. The only material in the building that was found to contain chrysotile fibers was the vinyl floor tile. The fiber content of a floor tile was analyzed with the ATEM and showed very abundant chrysotile fibers (Fig. 1, c and C). The owner of the building confirmed that the 5400 m^2 of floor were covered with asbestos vinyl tiles. These tiles were black and showed a decorative relief on their surface. Damage to some tiles was clearly apparent (Fig. 3). In the absence of any other explanation, we concluded that the short chrysotile fibers present in the air of the building had escaped from the vinyl matrix of the floor tiles. The fact that the highest concentrations were measured in the workshop on the third floor, where the activity was greatest, reinforced our conclusions. It might be hypothesized that, in this workshop, breakdown forces such as walking, scraping, and machine scrubbing were higher than in other places. High activity might also be an explanation for the higher concentration of airborne crocidolite at this site. The company that occupies this building now intends to cover the asbestos floor tiles with another flooring material.

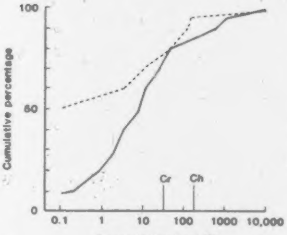

Fig. 2. Distribution of maximum concentrations of airborne amphibole-type asbestos fibers measured inside 36 buildings sprayed with a material containing amphibole-type asbestos (dashed line). Corresponding curve for chrysotile asbestos inside 58 buildings (solid line). The vertical lines indicate the maximum concentrations of airborne asbestos (*Cr* for crocidolite and *Ch* for chrysotile) fibers inside the building examined in this study.

It is well known that the building industry is the primary consumer of asbestos products, such as asbestos-cement pipes, asbestos-cement sheets for roofing and cladding, asbestos vinyl and asphalt floor tiles, insulation products, special-purpose decorative textiles, and asbestos-coating and paint compounds (*8*). The interest of environmentalists in possible indoor airborne asbestos pollution caused by the weathering of asbestos-containing materials began in the 1970's. Considerable attention has been devoted to buildings insulated with sprayed asbestos, where the concentrations of indoor airborne asbestos can be several orders of magnitude higher than the ambient background (*3, 9*). Some countries such as the United States and France have now banned the use of spray-applied asbestos-containing materials for insulation in buildings.

It has been reported that the sanding of old asbestos floor tiles that are to be replaced is an important source of asbestos exposure (*10*). To our knowledge, this report presents the first measurement of elevated concentrations of indoor airborne asbestos associated with the weathering of asbestos floor tiles during their service life. Daly *et al.* (*11*) have predicted that the average asbestos concentration in the air above an asbestos floor in service can theoretically be increased by 80 ng/m^3. Some concentrations measured in this particular building were close to the predicted level of 80 ng/m^3. Up to now, in spite of this prediction, the presence of asbestos flooring within a building has not been considered a serious source of potential indoor airborne asbestos. In the Environmental Protection Agency's control program in schools (*1*), the nature of the floor is not taken into consideration. In their survey of the asbestos-containing materials in 336 schools in Vermont, Novick *et al.* (*12*) did not report the presence of asbestos floor materials. In France, up to now, our measurement program in buildings was not designed to document the presence or absence of asbestos floor tile.

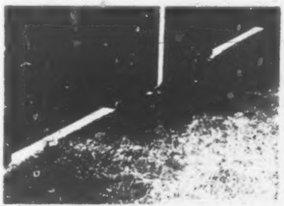

Fig. 3. View of the asbestos vinyl flooring in the building. Note the toning down of the black color and of the surface relief, as well as scraping marks.

The weathering of asbestos flooring under normal use patterns can yield concentrations of indoor airborne asbestos similar to those measured in sprayed buildings (Fig. 2), which are the subject of much concern. In 1976, flooring materials represented about 15 percent of the total U.S. market for asbestos, making it the third largest asbestos consumer, after roofing and asbestos-cement pipes (*8*). If this first measurement is confirmed in other places and by other laboratories, the use of asbestos flooring, a very common practice, could become an important environmental issue.

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27 October 1981; revised 5 February 1982

York River Destratification: An Estuary-Subestuary Interaction

Abstract. *Destratification in the York River during high spring tides is the result of the interruption of normal two-layer estuarine flow by the advection of relatively fresh water into the river mouth from the Chesapeake Bay. This advection is due to the presence of a longitudinal salinity gradient in the bay and a difference in the tidal current phase between the river and the bay. Similar behavior is seen in other subestuaries of the Chesapeake Bay and may be common in subestuary-estuary interactions.*

Vertical homogeneity in subestuaries of the Chesapeake Bay, which normally exhibit moderate stratification, has been shown by Haas (*1*) to be correlated with high spring tides. Identified by a surface-to-bottom salinity difference of less than 1 per mil in contrast to normal values as high as 10 per mil, these episodes have been termed destratification events (*2*). For example, the lower York River becomes vertically homogeneous 3 to 4 days after the predicted tide height exceeds 0.8 m (*1*), and homogeneity persists for three or more days. These events are not correlated with changes in the flow of fresh water into the river (*1*). Some of the significant consequences of destratification events in the York River include a periodic resupply of oxygen in the bottom water with an accompanying renewal of nutrients near the surface (*3*) and changes in primary productivity including blooms of dinoflagellates and other phytoplankton (*4*).

Two theoretical discussions of spring-neap tidally related stratification variations have been presented (*5*). Both of these models describe reductions in stratification that coincide with the occurrence of strong tidal currents and do not persist in the absence of such currents. This coincidence is in contrast to destratification in the lower York River, where vertical homogeneity first appears a few days after the onset of strong tidal currents and persists for several days thereafter (*1, 2*).

A conceptual model for the onset and disappearance of vertical homogeneity in the York River is as follows. (i) Destratification commences when spring tides exceed a critical height and relatively fresh water from the Chesapeake Bay is advected into the mouth of the York River. (ii) This produces a reduction or possibly a reversal of the pressure gradient driving estuarine circulation. The concomitant diminution of two-layer circulation reduces the tendency toward stratification by limiting the importation of more saline bottom water. (iii) This permits the establishment of homogeneity by the unopposed action of normal mixing processes enhanced by strong spring tidal currents. (iv) Destratification ceases when the decrease in tide height after spring tides halts the advection of the fresher water into the York River. (v) This allows the reestablishment of a normal horizontal salinity gradient, which produces the eventual reinitiation of two-layer estuarine circulation and vertical salinity stratification.

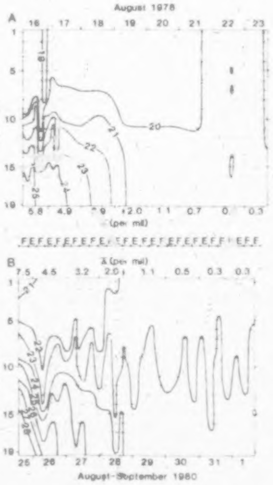

Fig. 1. Salinity data (per mil) from the York River mouth for the periods 16 through 23 August 1978 (A) and 25 August through September 1980 (B). The arrows indicates the dates of maximum spring tide; $\bar{\Delta}$ is the daily mean of differences in salinity from 1 m to the bottom. Periods of ebb (*E*) and flood (*F*) are indicated. Points indicate measurements (*11*).

This hypothesis developed from an examination of salinity data (Fig. 1, A and B) collected during intensive studies of two destratification events that were predicted on the basis of earlier work (*1, 2*). The intrusion of relatively fresh water, which initiated the destratification process, is indicated by the sharp downward displacement of isohalines on 16 August 1978 and 26 August 1980. In each case, this was followed by a progressive reduction of stratification in the water column. As expected, the introduction of fresher water into the river mouth caused a reversal of the longitudinal salinity gradient, producing a midriver salinity maximum. This condition is illustrated in Table 1, where York River salinity values at 1-m depth are shown for the period from 0 to 3 days after the intrusion of fresher water observed on 25 August 1980 (Fig. 1B). The data indicate a reversal of the normal longitudinal salinity gradient as far as 18 km upriver. A similar reversal was observed on several occasions between 15 and 20 August 1978 (*2*).

The reversal of the longitudinal salinity gradient is also evident from the behavior of the isohaline at 23 per mil in the 1980 data (Fig. 1B). The assumption is made that the salinity changes at the station are caused in large part by the advection of water of differing salinity up and down the river by tidal currents. Depressions in the isohaline, indicating the presence of fresher water, coincide with slack before ebb through 28 August, the date of highest tidal heights. After that date, the isohaline at 23 per mil shows a phase reversal. The depressions are coincident with slack before flood, indicating the reestablishment of the normal longitudinal salinity gradient. While tidal heights were increasing, there was a continuing source of fresher water. As tidal heights recede, more saline water is once again present in the river mouth.

The only reasonable source for the relatively fresh water is the Chesapeake Bay. An upriver source is discounted first because the water is introduced into the river mouth on flood tide (Fig. 1B) and second because the nearest riverine source of water of comparable salinity is

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Mr. **Fuqua**. Dr. Alter.

Dr. **Alter**. Mr. Chairman, members of the committee, I am Ward Alter, president of Terradex Corp. I am wondering if we could put a few of these transparencies up on that projector. It might be helpful. I can speak from the tables in my testimony, but not——

Dr. **Nero**. Do you want me to help with that?

Dr. **Alter**. Well, if you want to, Tony.

Terradex Corp. was formed about 10 years ago, and we are specialists in measuring radon for various applications in air, in soil, and in water. We have made perhaps more radon measurements than any other organization in the world.

I would like to tell you what I am going to cover. First, a look at the relative radiation exposure to the public; second, some of the methods that are now in use to measure radon indoors; third, the results of measurement in homes in other countries, results similar in the United States, and then some observations and recommendations.

The next, please.

This is a chart of the per capita exposure to the public from all sources of radiation. It's obtained from the United Kingdom. I will not go into any of these things in any detail except for the radon part of it, but it is noteworthy to indicate that the radon decay products are the largest single source of radiation to the public.

Radon, as has been pointed out, is a colorless, odorless gas that originates from uranium, which is a ubiquitous element in many materials. It enters the home from soil, from water, from building materials. Energy conservation, tightening of homes, increases radon levels, as well as other pollutants. And like other pollutants the concentration of radon is much higher indoors than outdoors.

Radon decay products are trapped in the lung. They are known to cause lung cancer from experience with uranium mining industry. In fact, the risk related to exposure is fairly well known in terms of lung cancer. The population exposure, however, is not as well known but is, in fact, the real exposure to the public at large.

If you look at this chart, you will observe that the largest exposure is perhaps the least researched and the least regulated. As an example, let's take the one on the bottom on nuclear power. The ratio of the exposure is about a factor of 250, and yet I am almost certain that the spending on research for safety and radiation-related reasons is a factor of 250 at least the other way. I am just pointing out the large disparity in terms of the research and the dollars versus the exposure risk for radiation.

The radon problem has been recognized outside of the United States in many countries, including Great Britain, France, Germany, Switzerland, Sweden, Canada, to name a few. These countries have started regional and national surveys to see what the levels are in their homes.

The practicality of such surveys has—it's been made possible by the introduction of new radon measuring techniques. Previous methods are very adequate for measuring radon and decay products, but in fact they are too expensive for large-scale work.

Our company has pioneered in the development of small passive devices—this is a typical example of such a device—which can be mailed around to the population which can be used accurately and inexpensively to look at total population exposure. All of the countries that I have mentioned are either using our technology or have duplicated our technology for their own use.

This chart—if you will leave that on one, please—is the real world of indoor radon and is based only on our own experience, not on the experience of others. I regret that the Canadian numbers are in error. There have been 546 measurements made. The highest measurement was 34 picocuries per liter and the percent greater than 4 picocuries are 21. The total number at the bottom is 48,612.

What we have listed here are the total number of measurements, the maximum reading in any country that we have seen, and then taken each country's number and compared it to a figure of 4 picocuries per liter.

It is perhaps helpful to know, just for calibration purposes, that the lung cancer risk of living in a 1 picocurie per liter house is roughly equivalent to smoking one cigarette per day. The 4 picocurie per liter limit, which we have in the last column, is based on an EPA limit for indoor air in houses which are located near abandoned uranium mill tailing sites.

In this case I would like you to notice the very large amount of data from the pilot program in Sweden, about 47,000 measurements. Note the record indoor level, which is disaster for the people living in that house. Note that 81 percent of the measurements exceed the 4 picocurie per liter standard. In addition, we have observed from the data that 14 percent of the measurements exceed 20 picocuries per liter, which you will recognize is roughly equivalent to smoking a pack of cigarettes per day.

All of the surveys have appreciable numbers greater than 4 picocuries per liter. Let me give as an example, however, Sweden, which may be helpful a little bit to us here. They have a national program to handle this problem. They have assigned specific responsibility to agencies in the country. They have set standards for indoor radon. If you have more than 20 picocuries per liter in your house, it is considered unsanitary.

For example, new houses cannot be built which have greater than 4 picocuries per liter. Subsidies and low interest loans are given to the population for remedial action, if you have an unsanitary house, and there is a lot of public information been given to the Swedish people in terms of this hazard.

The Swedish and the other data are also strongly correlated to the geology. In fact, before this survey was done most of the Swedish experts believed that the indoor levels were caused by building materials. They have now found that most of the indoor levels are caused by building over granites and shales and other formations which are high in uranium and high in radon. The problems, of course, in Sweden, as elsewhere, are made worse by energy conservation measures in the cold climate.

Could I have the next chart, please?

In the United States, reaction to this problem has been slow and the data are few. These again are our own measurements. They don't include the measurements of others. You will notice that we are looking at about 2,500 measurements compared to maybe 50,000 elsewhere.

There are, however, appreciable fractions in these various sections greater than the 4-picocurie-per-liter standard, even though those houses are nowhere near abandoned mill tailing sites.

As a special example, in Pennsylvania about 15 percent of the houses in that small survey exceed the 20 picocurie per liter limit, and as I have mentioned before, 20 picocuries per liter would give a family a lifetime exposure very comparable to the lifetime exposure of miners who are now dying of lung cancer.

In fact, one can take a look at data like this and predict just from the high readings that thousands of lung cancers will occur using the known risk estimates from the EPA. We simply don't know enough about the total population.

The U.S. data are also strongly correlated with geology. There are many other effects, of course, such as the type of construction, the house, the air change rates, and so on, but it is well known that sealing the buildings will increase radon levels.

We found that underground buildings, subterranean homes and so on are particularly bad because of the proximity to soil. We can't make any generalizations about the country from these limited data. The 12 percent under the total is simply a weighted average. But we can define some high areas: certainly Pennsylvania, parts of the Northeast, parts of New England, parts of Florida, where uranium occurs in phosphates, uranium-bearing portions of the United States and the West and elsewhere; in fact, formations—rock formations which have uranium occur in almost every State in the Union as defined by Department of Energy measurements.

Finally, then, I would like to summarize with a few observations. Could I have the next——

The data in the United States and elsewhere indicate a strong regional geological influence in radon levels, but no dwelling is necessarily immune from the radon hazard. No private industry is to blame for radon levels, since radon comes from natural sources.

Any action to decrease air change rates to accomplish energy conservation will increase the radon hazard, but available technology for remedial action can also reduce the hazard.

Good methods exist to measure radon and its decay products. We feel that research and measurement methods is complete.

Next, please.

We recommend first a well-designed national pilot program to determine regional and population radon exposure levels and to determine if more work is needed; second, remedial action research on methods to economically reduce radon and other indoor pollution while maximizing energy conservation; third, a carefully thought out program to inform the U.S. public about indoor air quality problems, including the radon hazard; and finally, adoption of indoor radon standards and appropriate legislation.

Thank you.

[The prepared statement of Dr. Alter follows:]

Written Statement
of
Dr. H. Ward Alter, President
Terradex Corporation
for presentation to the
Joint Hearing of the
Subcommittee on Energy Development and Application
and
Subcommittee on Natural Resources, Agriculture Research and Environment
of the
Committee on Science and Technology
of the
U.S. House of Representatives
August 2, 1983
Subject:
INDOOR AIR QUALITY RESEARCH: CURRENT STATUS AND FUTURE NEEDS

I. Relative Radiation Exposure to the Public

II. Indoor Radon Measurement Methods

III. Indoor Radon Measurement Results in Other Countries

IV. Indoor Radon Measurement Results in the U.S.

V. Observations and Recommendations

I. Relative Radiation Exposure to the Public

Annual radiation exposures per capita by natural or artificial sources are given in Table 1.

TABLE 1

ANNUAL RADIATION EXPOSURE FROM ALL SOURCES

Source	Milli-rem
*Radon Decay Products	80
Medical Irradiation	50
*Terrestrial Gamma Rays	38
*Internal Irradiation	37
*Cosmic Radiation	31
Fallout	1
Occupational Exposure	0.9
Miscellaneous Sources	0.8
Nuclear Power	0.3

*"Natural" Radiation

Data from UK NRPB Bulletin 39

The sources of indoor exposure are cosmic rays, terrestrial gamma rays and the decay products of radon-222. The main source of gamma ray exposure is the radionuclide content of building materials with a minor contribution from underlying soil and rock. The radon decay products in a home arise from the entry into the home of radon gas. The primary sources of radon gas are the soil and rocks upon which the house is built and well water derived from the underlying formations. A special and relatively uncommon source is from building materials having higher-than-normal radium contents. Energy conservation methods which reduce the air change rate of a building can also increase the radon concentration regardless of source. Indoor radon levels are generally several times higher than those measured outdoors.

The radon decay products are known to cause lung cancer from a large body of information on uranium miner lung cancer incidence caused by breathing relatively high levels of radon decay products during the course of their work. The risk of lung cancer related to radon decay product exposure is relatively well known and can be applied to the population as a whole. In general, risks are better known than the exposure and more research is necessary to establish the population exposure.

Most of us are aware of the great efforts that are applied by the federal and state governments and the nuclear power industry to protect the public from radiation released to the environment by the nuclear industry. Indeed a large fraction of the cost of nuclear power plants is the result of radiation safety compliance regulations. The Nuclear Regulatory Commission is, for example, a federal agency completely committed to radiation safety. Yet, referring again to Table 1, the radiation exposure of the population to radon decay products exceeds exposure from the nuclear power industry by a factor of 250.

This single largest source of radiation exposure to the population, namely radon decay products, is the least researched and least regulated. The annual spending for research and control of these various exposures in the U.S. does not match the severity of the exposure to the general population. We need only to observe that the $3.6 million appropriated by the House for Indoor Air Quality research is dwarfed by the NRC proposed funding of $467 million in FY 84, or the tens of millions of dollars authorized for research on specific cleanup of sites or radioactive waste disposal methods. We do not disapprove of the nuclear related spending; we wish only to emphasize the disparity in dollars vs. risk.

II. Indoor Radon Measurement Methods

The recognition of the relative exposure problem has stimulated national and regional indoor radon surveys in other countries; UK, France, Germany, Switzerland, Italy, Sweden and Norway. These larger scale surveys have been made practical by the use of new radon measurement techniques.

Many tested methods are available to measure the concentration of radon and its decay products, but, until a few years ago, large scale radon measurements were impractical because of expense. Our Company has pioneered in the development of accurate, yet inexpensive, detectors for indoor radon. These small passive detectors measure the time-averaged radon concentration over the period of time they are placed indoors. They can be easily mailed to the homeowner and are intended for use by the average person. It should be noted that the countries mentioned above are either using our detectors or have duplicated our technology for their own use.

Precise methods for radon measurement are readily available for large scale programs. Some of the results are described below.

III. Indoor Radon Measurement Results in Other Countries

The "real world" of indoor radon levels is shown first for countries other than the U.S. to illustrate the magnitude of the indoor radon survey work in progress. The results are based on our own experience; more data will be available in the future from other programs.

Table 2

INDOOR RADON RESULTS
OTHER COUNTRIES

Location	Number of Measurements	Highest Reading (pCi/l)	Percent Greater Than 4 pCi/l
Canada	422	15	16
Switzerland	634	729	62
Norway	293	288	58
Italy	67	60	28
Sweden	47072	1140	81
TOTAL	48488		

Indoor radon results, outside the U.S., from our experience, are shown in Table 2 with radon values given in picoCuries per liter (pCi/l). The table shows the country involved, the number of measurements made, the highest reading recorded, and the percent of measurements exceeding the level of 4 pCi/l. The 4 pCi/l figure is based on the "target limit" for indoor radon concentrations in buildings near abandoned uranium mill tailings sites in the U.S. This standard has recently been adopted and published by the U.S. EPA.(1) At 4 pCi/l the lung cancer risk is roughly comparable to that of smoking 4 cigarettes per day.

Several of the programs from other countries were directed at "problem" homes in specific areas, and, are not necessarily representative of the country as a whole.

Table 2 shows first the overwhelming preponderance of data from Sweden. The highest readings in a number of Swedish homes are very serious based on the unextrapolated risk estimates from uranium mining experience. We note that all countries have an appreciable fraction of houses which exceed the EPA limit.

The most coherent and comprehensive approach to assessing the radon hazard has been adopted in Sweden. Federal responsibility for indoor radiation protection has been assigned to specific agencies. Standards have been set for radon decay products in all housing. A building is regarded as unsanitary when radon levels exceed about 20 pCi/l. Incidentally, 14% of the Swedish measurements exceed that level. The level of radon in new Swedish housing cannot exceed about 4 pCi/l. Specific subsidies and low interest loans are available for remedial action on "unsanitary" homes. A large public relations effort has thoroughly informed the Swedish public about the radon hazard and they are taking direct action to solve this urgent public health problem.

(1) EPA limit based on 40 CFR Part 192 Fed. Reg. Vol.48 No.3, Jan. 5, 1983.

The 47,000 Swedish measurements further indicate that high radon levels are associated with homes built over granites and shales. The problems are exacerbated by the tight construction in new Swedish buildings to achieve energy conservation in a cold climate.

It can also be noted that the high levels in Switzerland may reflect the use of tunnels and caves for much Swiss industry. Since most radon comes from rocks and soil, underground buildings such as those in Switzerland are expected to have high radon levels.

IV. Indoor Radon Results in the U.S.

The U.S. has been slow to recognize radon as a significant public health problem and as a result very few U.S. measurements have been made. Table 3 shows results of measurements made by us in various regions or states of the U.S. We do not include the limited number of measurements made by other investigators.

Table 3

INDOOR RADON RESULTS
UNITED STATES

Location	Number of Measurements	Highest Reading (pCi/l)	Percent Greater Than 4 pCi/l
N. California	80	7.4	15
Midwest	64	7.4	20
South	304	2.7	0
N. East	133	77	20
New York	413	50	15
Pennsylvania	249	91	42
Maine	427	133	21
Other U.S.(1)	826	-	-
TOTAL	2496	133	12

Table 3 shows that appreciable fractions of U.S. houses exceed the 4 pCi/l EPA limit even though these houses are far removed from abandoned uranium mine tailings. Higher readings seem also to be correlated with the colder northern parts of the country. Another analysis of the Pennsylvania data shows that 15% of the readings exceed 20 pCi/l. Lifetime exposure of a family to this level, namely 20 pCi/l, gives a total exposure in the range of that known to cause lung cancer in uranium miners. These statistics imply that thousands of radon-related lung cancer cases may occur in Pennsylvania, for example, unless appropriate measurement and remedial action is undertaken. (This risk compares with less than one possible cancer death calculated from the recent Three Mile Island nuclear accident in the same area.) The U.S. data are also

(1) Data not released by clients

strongly correlated with geology, the radon source being soil or well water derived from underlying rock formations. Radon levels will also become higher as buildings are sealed and particularly for new energy conserving housing and using new construction practices. Underground housing would also be expected to have high radon levels due to the increased proximity to soil around the buildings.

The scarcity of U.S. data does not permit generalizations about the U.S. problem, and the final total statistics showing 12% of the total exceeding the standard do not reflect the U.S. as a whole. Several regions, however, can be identified from the present data base as having higher than normal hazards. These include Pennsylvania and the Northeast, parts of New England, and granitic or uranium-bearing areas in the West or elsewhere. Phosphate-rich rocks in Florida, containing uranium, are also a known significant source for indoor radon.

Uranium-bearing formations giving rise to radon occur in many of the States. Maps showing some of these uraniferous areas are available from the Department of Energy and can be of some help in localizing planned surveys.

V. Observations and Recommendations

- Data in the U.S. and elsewhere indicate a strong regional geological influence on radon levels, but no dwelling is necessarily immune from the radon hazard.

- No private industry is to blame for radon levels since radon comes from natural sources.

- Any action to decrease air change rates to accomplish energy conservation will increase the radon hazard, but available technology for remedial action can also reduce the hazard.

- Good methods exist to measure radon and its decay products. We feel research on measurement methods is complete.

- We recommend:

  (a) a well-designed national pilot program to determine regional and population radon exposure levels and to determine if more work is needed.

  (b) remedial action research on methods to economically reduce radon and other indoor pollution while maximizing conservation.

  (c) a carefully thought-out program to inform the U.S. public about indoor air quality problems, including the radon hazard.

  (d) adoption of indoor radon standards and appropriate legislation.

Mr. **Fuqua**. Thank you very much, Dr. Alter.

Dr. Hess.

Dr. **Hess**. I have some slides to show as well. Perhaps——

Mr. **Fuqua**. Are they included in your statement?

Dr. **Hess**. I have a combined statement and brochure. The slides are duplicates from the brochure, which is attached to the statement, so that it is possible to see the slides either way.

Are you ready? This slide shows the chemical element radon as part of a radioactive decay series for uranium. As you can see, uranium decays through a great many elements. Radon, however, is the only one which is a gas, and this leads to its interesting and problematical quality that it can move around a great deal more easily than the other elements do.

Radon itself is not the end of the radioactive series but leads into a whole set of radioactive elements, which are called the radon daughters. And radon itself has a half-life of 4 days. Could I have the next slide?

My studies have largely been in the State of Maine and have originated in measurements of radon and water. This is the result of more than 2,000 measurements of radon and water and shows the places in Maine which have radon and water greater than 10,000—say 3,000 to 10,000 picocuries per liter as the center of that scale.

What you can see here is the large dots represent concentrations that are 30,000, 10,000 and so on picocuries per liter. The colored regions that are shown in this slide are granitic areas, and I think you will see that the larger dots lie over the orange and red granitic areas that are shown in this slide. Could I have the next slide?

In New England the granitic areas are widespread, and all of these shaded areas are rock formations which tend to produce radon in houses, either through water or through direct leakage of the radon through the basement of the house. Could I have the next slide?

As was mentioned by Ward Alter, the—it is well known that radon exposure, which leads to a radiation exposure to the interior of the lung, can result in lung cancer for miners. And this slide shows the lung cancer risk for miners in the United States that were exposed to radon as part of working in a poorly ventilated mine.

The risk on the left-hand edge there represents their chance of getting lung cancer, and along the horizontal axis shows the total exposure that they receive from breathing radon daughters while they were working in the mine.

I should mention that in—as part of our measurements in Maine homes we have turned up a few houses that would violate the standards that OSHA now has for uranium miners and with the time duration that people have when they are in houses would place their exposure on this line.

Not extrapolating in any sense, but using the numbers in between the points, we can calculate the risk to the individual in certain houses in Maine. In this case, the highest house that we have seen is 133 picocuries per liter and the OSHA standard is around 30 picocuries per liter, so we have almost a factor of 4 greater radon in that home than would be allowed in a mine. Can I have the next slide?

Here are some of the standards that have been proposed in different areas for radon in houses. The—as you can see, these standards vary, depending upon whether it is retrofitting old houses or whether it is new house construction. The—also from country to country. But the numbers are in the range from about 2 up to about 30 picocuries per liter, and at the high end of the scale usually the action is to be taken immediately, where they would actually warn the people and ask them to open up their house and ventilate it. Can I have the next slide?

This is a pictorial showing where the radon can get into a house. It shows little arrows for the radon gas coming out of the ground. Because uranium and radium are found in the soil, the radon can come out of the soil and penetrate through the walls of the house and come through the water that is taken out of the ground and can come in through openings or cracks in the basement or through greenhouse that has soil in it. There are examples of—that very hothouse that I was talking about a little while ago has a greenhouse where the soil is actually up inside the greenhouse and so the radon can come right up through the soil itself. Can I have the next slide?

To show ventilation effects, we actually measured some houses with radon in their water. And you can see here on a horizontal scale where we can estimate the air changes per hour, and the vertical scale gives the picocuries of radon per liter of air.

And what this shows is the experimental data which verifies the idea that the more you seal up a house—in other words, the slower the ventilation rate is—the greater the radon levels will be. So as you go from right to left, you're essentially sealing up the house and reducing the amount of air and the concentration of radon in the house goes up.

And this is the basis for saying that radon can be increased by a factor of more than six by merely sealing up the house. Now this assumes that you are going to have the same amount of radon coming in and all you are really doing is changing the rate of ventilation for that house. And these are actually points that were homes measured in Maine. Next slide?

Another point that I wanted to make is that there is a great need to try to find out if the exposure that we are calculating for people, the dose that they are receiving is causing a higher lung cancer rate, the way we would predict from the theoretical point of view about miners.

And so to try to test this we did some very primitive epidemiology a few years ago, where we took the counties in Maine, took the radon in water in these counties, and found the average value for each county.

And you can see here the average value of radon in nanocuries per liter shown with different color schemes. The highest counties are the black ones, and then cross-hatched—vertical cross-hatches say 12,000 to 15,000 picocuries per liter, and the lowest is in Aroostook County, the clear one at the top.

When we took these average values by counties and correlated it against National Cancer Institute lung cancer data, you can see that result on the next slide. What we found was a significant correlation for radon and water by county versus lung cancer deaths. And this used data that was prepared and age adjusted by the National Cancer Institute as part of the Mason and McKay study.

The women's lung cancer rates are lower. They are shown in the open dots there. And they are lower because the people that were used for this study died in the late fifties, from 50 to 69, and would have been in their sixties in that—it means that most of them didn't smoke. And the men in this study were exposed, of course, to higher rates of smoking and other occupational causes for lung cancer.

This particular study is not a definitive study. It doesn't—it is not the kind of clinical study that we would advocate, but it shows at least that there may be something going on with these high areas for radon.

I would like to just state my conclusions. Radon is a natural element found in the ground, and it does get into buildings. Very high concentrations of radon are found in some of the geological areas of the United States, and it produces the highest radiation dose to the population.

Health implications are that this dose may be associated with substantial lung cancer risk. Methods are available to prevent the dose and risk by avoiding introduction of radon into houses and by ventilating the houses, if they already have radon.

Studies of national radon levels in water, soil gas and house air are needed to quantify the dose and risk to the U.S. population and to find high radon areas in each State. Experimental clinical studies of lung cancer risks associated with home radon should be started to determine if the risk is as high as is calculated.

I think that is all I would like to say.

Mr. Fuqua. Thank you very much, Dr. Hess.

[The prepared statement of Dr. Hess follows:]

Testimony of Charles T. Hess Ph.D.
Professor of Physics, University of Maine, Orono, Maine

Regarding: Indoor Air Quality Research, Current Status and Future Needs

Don Fuqua, Chairman of Subcommittee on Energy Development and Applications

James H. Scheuer, Chairman of Subcommittee on Natural Resources, Agricultural Research and Environment.

Chairman Fuqua and Chairman Scheuer and members of the committee, I am Dr. C.T. Hess from the University of Maine. I am here to speak about the research concerning the elevated levels of radioactive radon gas in the air and water of the State of Maine and how it relates to indoor air radon in the United States.

The radioactive chemical element radon is one step in the radioactive decay series of uranium (Page 2, Radon in Water and Air). Both uranium and radium which preceed radon are found naturally in the rock and soil. As water and air pass through the rock and soil, underground radon mixes with them and is transported into houses. When this transported radon becomes mixed with the house air, it can decay to produce radioactive daughter elements which attach to the walls of the lung and expose the lung to a radioactive dose.

Studies of radon in ground water supplies and in the air of the houses using radon rich water have been in progress in Maine since 1968 and show that very high concentrations of dissolved radon are found in drilled wells in granite (up to 1,000,000 pCi/l). Correspondingly high levels of radon are found in the air of some Maine homes. In granitic areas, some of the air concentrations exceed the OSHA standards for radon in uranium mines. In the average well in Maine radon has a concentration of 10,000 pCi/l of water which will produce 1.0 pCi/l in the house air. In other non-granite areas of Maine groundwater values of 1000 pCi/l are typical (Page 3, Radon in Water and Air). Similar patterns of high water radon in granite areas are observed in New Hampshire, Rhode Island and Connecticut, Minnesota, California and Virginia.

The health implications of these high levels of radon are based on evidence of high levels of lung cancer in uranium miners and other hard rock miners who are exposed to radon in poorly ventilated mines. (Page 5, Radon in Water and Air). The studies are most reliable for 500 rems of exposure and higher and this exposure will be comparable to living in a house with 10 pCi/l in the air for 60 years. The lowest direct evidence of lung cancer is 40-50 rems of exposure which would be the same as 20 years in a house with 2 pCi/l (Page 6, Radon in Water and Air).

Dose calculations with existing data show that indoor radon from water and soil gas produce the largest radiation dose to the public, larger than medical radiation, other natural radiation, occupational radiation or nuclear fallout. The rough estimates of long term exposure to indoor radon yields doses sufficient to account for 5-20,000 excess lung cancers per year in the United States (Page 7, Radon in Water and Air).

High levels of radon in a house are a result of radon which escapes during use of water, radon from soil gas leaking into the basement or through the slab or floor of the house, or in exceptional cases, building materials. Thus, basements and water use rooms have higher levels of radon than the rest of the rooms, (Page 8, Radon in Water and Air). Construction methods which prevent seepage of soil gas and use of low radon water from surface supplies such as lakes or aerated or carbon filtered ground water can prevent the introduction of radon into the house (Page 11, Radon in Water and Air). Avoidance of building materials containing high radium will avoid further radon introductions.

Sealing houses to reduce the energy loss in house air will cause the buildup of radon by a factor of 2-6 times as much, increasing the dose. Reduction of radon can be done by increasing the ventilation, by opening windows or with an air to air heat exchanger. Buildings should be designed to have adequate ventilation and energy should be conserved by insulation rather than by sealing them up.

Conclusions:

1. Radon is found naturally in the ground and gets into buildings.
2. Very high concentrations of radon are found in some geological areas of the U.S. and it produces the highest radiation dose to the population.
3. Health implications are that this dose may be associated with a substantial lung cancer risk.
4. Methods are available to prevent the dose and risk by avoiding introduction of radon into houses and by ventilating the houses.
5. Studies of national radon levels in water, soil gas, and house air are needed to quantify the dose and risk to the United States population, and to find high radon areas in each state.
6. Experimental clinical studies of lung cancer risk associated with home radon should be started to determine if the risk is as high as is calculated.

Biographical Sketch

Dr. C.T. Hess is a Professor of Physics from the University of Maine, Orono, Maine. He has studied radon in water and air since 1972 with grants from the Office of Water Research and Technology of the U.S. Dept. of Interior, the United States Environmental Protection Agency, and from The Maine Department of Human Services. Several papers associated with this work have been published in Natural Radiation Environment III, Health Physics, and Environment International. Results have been presented at scientific meetings in the United States and abroad. In 1980-1981 he took a sabbatical leave at the University of Texas School of Public Health at Houston to study radon with Dr. Gesell. In 1983 he was chairman of the Occurrence Committee for the National Workshop on Radioactivity in Drinking Water sponsored by the U.S. Environmental Protection Agency.

Resource Highlights

RADON IN WATER AND AIR

Health Risks and Control Measures

AN INFORMATIONAL
DIGEST PREPARED AND
DISTRIBUTED BY

THE LAND AND WATER
RESOURCES CENTER,
UNIVERSITY OF MAINE
AT ORONO

and

THE DIVISION OF
HEALTH ENGINEERING,
MAINE DEPARTMENT OF
HUMAN SERVICES

February, 1983

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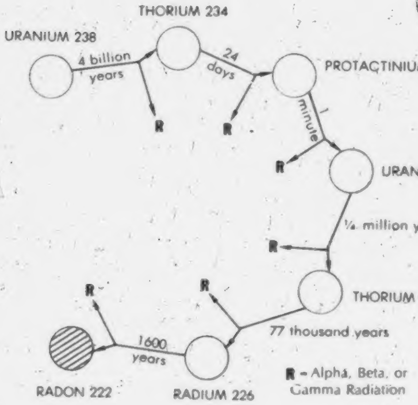
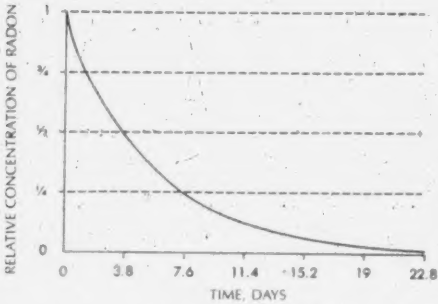
WHAT IS RADON?

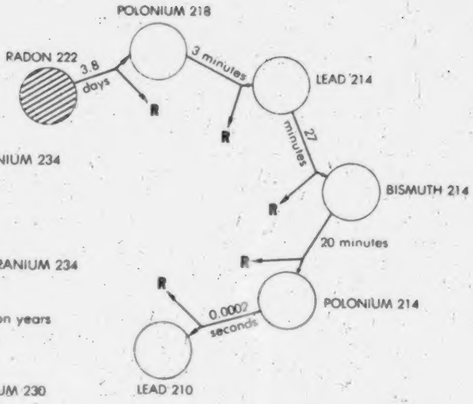

URANIUM 238
4 billion years
THORIUM 234
24 days
PROTACTINIUM 234
1 minute
URANIUM 234
¼ million years
THORIUM 230
77 thousand years
RADIUM 226
1600 years
RADON 222
R
R = Alpha, Beta, or Gamma Radiation

FORMATION OF RADON

Radon is a naturally occurring radioactive gas found in low concentrations almost everywhere on earth. It is colorless, odorless, and chemically inert, like helium, neon, and the other so-called "noble" gases. It is fairly soluble in water.



DECAY CURVE FOR RADON


RADON 222
3.8 days
POLONIUM 218
3 minutes
LEAD 214
27 minutes
BISMUTH 214
20 minutes
POLONIUM 214
0.0002 seconds
LEAD 210
R

RADON'S PROGENY

Radon is the immediate product of the radioactive decay of the element radium. However, radon is midway in a chain of radioactive transformations originating with uranium, which has such a long half-life as to have been present at the formation of the earth.

The chain of radioactive transformations does not end with radon. Indeed, it is the radioactive decay that can affect living organisms. Every atom of radon undergoes a series of transformations, emitting alpha, beta, and gamma radiation. The radioactive elements that result from the decay of radon are called "radon progeny" or, sometimes, "radon daughters". Because of these processes, when radon is present in air or water, radon progeny are also present.

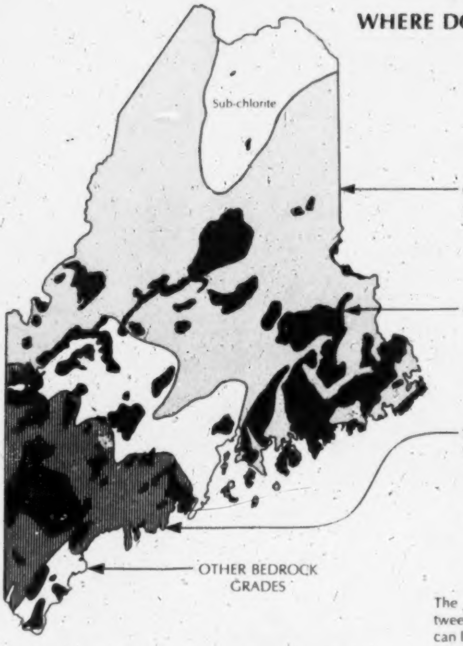
For purposes of clarity, the diagrams above have been simplified with respect to the by-products of the radioactive chain. The time information on the diagrams represents "half-lives". That is, these numbers indicate how long it takes for half the atoms of each element to decay.

The half-life for radon is 3.8 days. As the graph at left shows, every 3.8 days, the concentration of radon falls by a factor of one-half.

In a normal environmental situation, the decay of radon is accompanied by the continual replenishment of fresh radon. Thus the concentration of radon in water and air in the home does not follow the pattern shown in the graph.

Concentrations of radon progeny, which have half-lives ranging from fractions of a second to tens of minutes, generally follow the concentrations of the much longer-lived radon. Such concentrations may vary from the radon concentrations, however, depending on specific removal processes.

WHERE DO RADON LEVELS TEND TO BE HIGH?



	Number of wells Tested	Average Radioactivity of Well Water (pCi/L)*
CHLORITE ZONE (metasediments)	56	1,100
GRANITE	136	22,000
SILLIMANITE ZONE (Metasediments)	35	13,600

*pCi/L, the abbreviation for picoCuries per Liter, is used as the radiation unit of measure throughout this report. The prefix "pico" means a multiplication factor of .000001. A Curie is a commonly-used measurement of radioactivity.

ALL GROUNDWATER CONTAINS SOME RADON AND THEREFORE SOME DEGREE OF RADIOACTIVITY. RADON LEVELS VARY CONSIDERABLY FROM ONE AREA TO THE NEXT BECAUSE OF DIFFERENCES IN BEDROCK GEOLOGY. IN MAINE, SOME AREAS HAVE RELATIVELY HIGH RADON LEVELS.

The fact that radon is naturally present in well water (as well as the soil) has been known since the first decade of this century. It has only been in the last 20 years or so that an awareness has developed that radiation from natural sources may be high enough, in some cases, to represent health risks. In the 1960s and early 1970s it was discovered that the radioactivity of water from many wells in Maine were above some suggested drinking water standards. Then in the late 1970s, researchers at the University of Maine at Orono found:

- Radon is present in Maine's well water in varying amounts. Radioactivity of the well water from 2,000 wells tested averaged approximately 10,000 pCi/L. (These wells did not represent a random sampling.)
- In general, radon concentrations are highest in granite bedrock.
- Public water supplies have relatively low radon levels.

The map and figures above summarize the relationship between radioactivity of well water and bedrock geology. As can be seen, radon levels are somewhat high in "sillimanite" zones. (Sillimanite is a grade of metamorphized sedimentary rock.) The number of tested wells with known geological conditions represents only a fraction of the 2,000 wells that have had water tested for radon over the last decade.

The bedrock geology of Maine is quite complex, and the map above represents a simplification of actual conditions. Generally, the granite and sillimanite bedrocks in the southern part of the state have been buried deep, in the geologic past, and been subject to considerable heat and pressure.

The relationship between granite bedrock and high radon levels occurs in other sections of the United States and throughout the world. Indeed, it can be anticipated that radon levels like those found in Maine may exist in other sections of Northern New England and along the eastern side of the Appalachian Mountains.

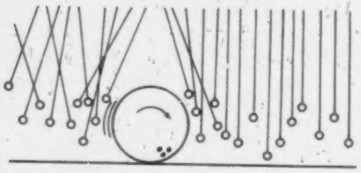
As soon as groundwater is brought to the surface and exposed to the air, it begins to lose radon to the air. This is why radon levels in lakes and other surface waters are low. This is also why water from public water supplies—stored in elevated tanks or reservoirs before it is distributed—has low radon levels even where the water was originally obtained from wells.

HEALTH EFFECTS OF RADON

What happens when radon and radon progeny are inhaled or ingested? Because radon is chemically inert, radon that is inhaled is also exhaled. The radon progeny, however, are chemically active, being metals, such as lead, bismuth, and polonium. These elements will stick to anything with which they come into contact, such as particulates in the air and on furniture and room surfaces. When inhaled, 30% of the radon progeny, both attached to particulates and free, come into contact with air passageways in the lungs and adhere to the surfaces. Radiation from such radon progeny can strike and break molecules in living cells.

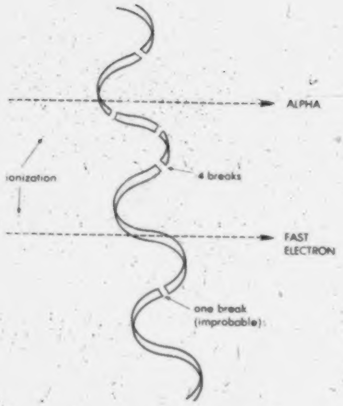
Radon progeny ingested with water cannot pass through the walls of the gut into the blood. However, radon itself can diffuse through the wall of the gut (or is burped out). The progeny of such radon can affect the stomach and other organs (but normally in such small amounts as to be insignificant compared with radon entering air passageways).

The health risks of radon and radon progeny are mainly due to the emission of alpha particles by several of the radon progeny. (An alpha particle is really a helium atom moving at high speed.) Alpha particles lose speed as they pass through matter and knock electrons off molecules of such matter. This process, called "ionization", is similar to a situation where a bowling ball would be slowed down by hitting marbles suspended on strings. Because the marbles have so much less mass than the bowling ball, the ball will only be stopped after hitting a great many marbles.



BOWLING BALL (ALPHA PARTICLE)
HITTING MARBLES (ELECTRONS)

Alpha particles have initial energies such that they slow to a halt after penetrating two or three inches of air. In liquid or solid matter, such as body tissue, the alpha range is much shorter (about one thousandth of an inch) because of the greater density of the matter the particles are passing through.



RADIATION EFFECTS
ON DNA MOLECULE

The knocking of electrons out of molecules can cause the molecules to be broken and changed. Some of the changes can be harmful to living tissue. For example, if the information in a DNA (genetic) molecule is changed, the functioning of a whole cell can be altered, particularly when it reproduces itself.

Beta and especially gamma radiation can penetrate far deeper into tissue than can alpha radiation. However, the density of ionization from beta and gamma radiation is much less than that from alpha particles. An alpha particle that passes through one of the big DNA molecules in a cell nucleus will probably break it in three or four places, while a fast electron from beta or the other electromagnetic gamma radiation will be likely to break it in at most one place—with a high probability of passing right through it with no hit at all. The biological harm per unit of energy absorbed from beta and gamma radiation is believed to be only one tenth or less than that of alpha particles.

Genetic molecules in tissue are frequently broken by random processes due to normal body heat and various chemicals, as well as by radiation. There are chemicals that repair single breaks, and a DNA molecule broken at one place can normally be repaired with a high probability of success. However, if it is broken in three or four places simultaneously, it may very well be put back together wrong, with possible ill effects on the cell it governs.

This ability of cells to repair themselves after minor damage from radiation lends some support to the notion that health impacts of low doses of beta and gamma radiation may become vanishingly small.

CONCLUSIONS ABOUT THE HEALTH RISKS FROM EXPOSURE TO RADON ARE DERIVED FROM 1) KNOWLEDGE ABOUT HOW RADIATION INTERACTS WITH TISSUE; 2) KNOWN EFFECTS OF HIGH DOSES OF RADIATION; AND 3) ASSUMPTIONS ABOUT HOW HIGH-DOSE HEALTH EFFECTS CAN BE EXTRAPOLATED DOWN TO LOW-DOSE EFFECTS.

There has been a very large amount of study given to the subject of the health effects of radiation. A comprehensive and up-to-date summary of knowledge on the subject is that presented in the report published by the National Academy of Sciences in 1972 and updated in 1980: *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.* The following discussion of health risks is based primarily upon the results described in that report.

Health Effects of High Radiation Doses

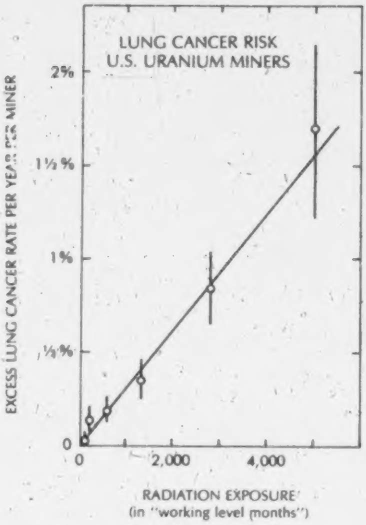
Much is known about the effects of high radiation doses on human beings. This information comes from mortality statistics of Japanese A-bomb survivors and of others subject to high doses of radiation before the health impacts were understood. These people included uranium miners in unventilated mines, workers painting watch dials with luminous paint containing radium, and persons treated with radiation therapy for non-mortal diseases.

Although there are other health effects from *very high* doses of radiation (i.e., those suffered by nuclear bomb victims), increased cancer risk is the only significant known health effect of radiation at levels comparable to those experienced in home environments. Moreover, scientists and people in public health agencies agree that the health risk from radon has mainly to do with airborne radon and air passages in the human body and the lungs. This is due to the constant exposure of breathing air containing radon.

There is no direct and conclusive evidence linking radon exposure in the home to increased incidence of cancer. Estimates of health risks from airborne radon have to be made on the basis of studies of people who have been exposed to high levels of radiation. The most useful of such studies appear to be those of underground miners.

Where workers in uranium and other mines have been exposed over long periods to high concentrations of airborne radon, they have had significantly high lung cancer rates. The graph was based on mortality rates of 4,000 miners who worked in improperly ventilated mines in the United States in the 1940s and 1950s. Up to 1974, there had been 135 lung cancer deaths in excess of the 16 that would have been predicted for the group with normal rates. The same relationship between lung cancer and airborne exposure has also been found in studies of workers in several different kinds of underground mines and in many countries.

The mortality rates of the miners show that there was a delay of from 10 to 25 years or more between the time of exposure and the appearance of lung cancer caused by such exposure. Miners are still dying from lung cancer caused by radiation exposure in the 1950s.



EXCESS LUNG CANCER MORTALITY AMONG URANIUM MINERS HAS BEEN PROPORTIONAL TO DEGREE OF RADIATION EXPOSURE.

The studies of uranium miners show that excess lung cancer mortality rates are proportional to radiation exposure at high doses. ~~Similar~~ studies have provided information on the effect of high-dose radiation on the stomach and other parts of the body.

Health Effects of Low Radiation Doses

For the purposes of this digest "high" radiation doses are those levels where a known relationship has been found between radiation exposure and increase in cancer mortality. Radiation exposure is commonly measured in "rems" and "millirems" (i.e., thousandths of rems). Conclusions from studies of miners are fairly definite for radiation exposures around 500 rems and over. Such exposure would be comparable to living in a house for 60 years with an airborne radon level of 10 pCi/L (picoCuries per Liter). Knowledge of health risks for low radiation exposure becomes more and more ambiguous at lower exposure levels, however. The lowest radiation exposure for which there is any direct evidence of excess lung cancer among miners is in the range of 40-50 rems. This exposure would be equivalent to living in a house for 20 years with an airborne radon level of 2 pCi/L.

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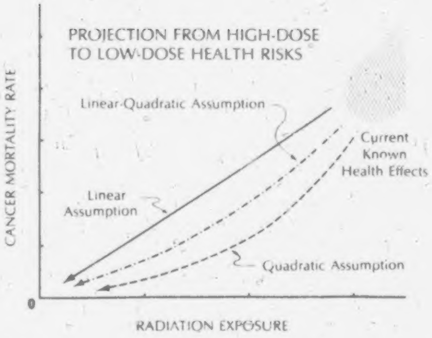
HEALTH EFFECTS (Cont.)

The projection of health risks from high radiation exposures to low exposures involves assumptions that tend to be more opinion than fact. Is the health risk from low-dose radiation simply proportional to known risks of high-dose radiation? That is, does a person exposed to one-hundredth the radiation have one-hundredth the health risk? Or is there a threshold below which radiation does not represent a health risk at all?

On the basis of experiments with animals and human cells, scientists are fairly well convinced that low-level radiation can cause cancer. But direct cause-effect information that would indicate the degree of risk is lacking now and may be for some time in the future. The problem is that incidence of cancer from other causes, such as smoking, simply overwhelms incidence from low-level radiation—making detection and statistical analysis unreliable. Indeed, the normal fluctuation of cancer rates between population groups exceeds the small increment that may be caused by low-level radiation.

The scientists are largely left, then, with the necessity of making assumptions on how the known risks at high radiation levels should be extrapolated down to low-dose levels. Current scientific opinion on this issue was recently described by Dr. Edward Webster, Professor of Radiology at the Harvard School of Medicine, and a member of the National Academy of Sciences committee working on the subject. Dr. Webster described three methods for projecting health risks from high-dose down to low-dose radiation:

1) The "linear" assumption projects health risks straight down from known risk levels to zero risk at zero exposure.
2) A "quadratic" assumption implies that the risk falls off at a substantially higher rate than the exposure.
3) A "linear-quadratic" assumption is simply the middle position between the other two.



Dr. Webster noted that the majority opinion of scientists on the National Academy of Sciences committee favors the "linear-quadratic" assumption for whole-body "gamma-type" radiation, (the kind of radiation that a worker in a nuclear power plant might be exposed to). The committee favors the linear assumption for risks from airborne (or waterborne) radon and "alpha-type" radiation.

The estimates given below of health risks from drinking waterborne radon or breathing airborne radon are based on the "linear" assumption. For reasons stated, the estimates cannot be considered exact. The uncertainties are so great that the actual risks might be double—or half—the estimated risks. Indeed, there may be synergetic health impacts from, say, exposure to airborne radon combined with smoking. Such potential impacts are completely unknown at this time.

Health Risks for People Exposed to Radon in the Home

For *drinking* water, if the linear assumption is used, UMO researchers estimate there would be an additional life-time risk of dying from stomach cancer in the neighborhood of 1% per 100,000 pCi/L. That is, if someone lived 60 years in a house with a radon level in the drinking water of 20,000 pCi/L, that person might have one chance in 500 of dying from stomach cancer resulting from the radon.

Waterborne radon levels over 100,000 pCi/L have been found in Maine, and one house had well water averaging approximately 700,000 pCi/L. The health risk of drinking water with such levels of radon would undoubtedly be considered significant enough to warrant corrective measures.

The risk of dying from lung cancer resulting from breathing *airborne* radon is estimated by UMO researchers to be 1% for each 4 pCi/L of lifetime exposure. Again, this estimate uses the linear assumption and must be considered imprecise. If the estimate is correct, a person living for 60 years in a house with an airborne radon level of 4 pCi/L would have one chance in 100 of dying from lung cancer from that cause.

An airborne radon level of 4 pCi/L is not at all unusual. UMO researchers have tested airborne radon levels in 85 homes in the state. About half of these were in granitic regions. The lowest level of airborne radon found was 0.5 pCi/L. In a few cases, airborne radon levels above 10 pCi/L were found, and in one case, the level was an extraordinary 100 pCi/L. (In uranium mines, airborne radon levels are held below 66 pCi/L.)

The significance of health risks from radon in any home is up to the individual to judge. Certainly an airborne radon level of 100 pCi/L would represent a significant health risk. But at the other end of the scale, some people could be more affected by worrying about the radon than by the radon itself. In the great majority of cases, there is no immediate urgency. Decades of exposure might involve significant risks, but generally not a few months or even a few years of exposure. (The long-term risks may be more significant in a rural state like Maine, where some people live many years in the same area and get their water from individual wells.)

PERSPECTIVE ON RISKS AND STANDARDS

As the table at right indicates, approximately 20% of deaths in the United States are currently due to cancer. About a quarter of these cancer deaths--approximately 100,000--are due to lung cancer.

There are many known causes of lung cancer besides airborne radon. Smoking is associated with 70% of lung cancer deaths. Indeed, the lung cancer rate for male smokers is 10.8 times the rate for non-smokers. And it has been found that among Japanese non-smoking women, lung cancer rates of wives of smokers are twice that of wives of non-smokers.

Other causes of lung cancer, many found in industrial settings, include: asbestos, arsenic compounds, chromate dust, nickel compounds, coal-tar fumes, isopropyl alcohol, petroleum oil mists, and products of burning coal. Wood smoke contains many of the same cancer-causing agents as tobacco smoke.

Just as radon in the home is only one of a number of indoor air pollutants, it is also only one of a number of low-level radiation sources in the environment. For most people, levels of radiation due to radon in the home are no more dangerous than a variety of other health risks. But the levels of radon in some Maine homes are producing radiation exposures far above that caused by other forms of radiation. A person living in a home with, say, 3 pCi/L of airborne radon is being exposed to around 3,000 millirems of radiation each year. And a person drinking water from a well with, say, 30,000 pCi/L in the water receives 900 millirems annually in his stomach. Such exposures, which are by no means uncommon, can be seen to be greater than the doses from all other average radiation doses.

Partly because of uncertainties about health effects of low level radiation, scientists and government agencies have been wary in setting standards for radon. Some standards for *airborne* radon are in use, however, as indicated in the table at right. The lack of a solid scientific basis for the standards is partly suggested by the way the 3 pCi/L standard was arrived at for houses built on uranium mine wastes in the United States. The threshold was apparently established, not because the risk of lung cancer was believed to disappear below the 3 pCi/L level, but because radon levels in some houses in the same region (and not built on mine wastes) were naturally that high and further reduction in the standard would involve more than removal of wastes for which the government was responsible.

For *waterborne* radon (i.e., radon in well water), no standard has received a consensus, at least partly because the health impacts are largely indirect and depend upon varying factors (such as ventilation and water-use habits). These are discussed in the following pages.

LEADING CAUSES OF DEATH IN THE U.S. IN 1978

Heart disease	730,000	(36%)
Cancer	400,000	(20%)
Stroke	106,000	
Motor vehicle accidents	54,000	
Pneumonia	52,000	
Diabetes	34,000	
Liver cirrhosis	30,000	
Arteriosclerosis	29,000	
Suicide	27,000	
Homocide	20,000	
Emphysema	16,000	
Accidental causes (not a complete listing)		
Falls	14,000	
Drowning	7,000	
Conflagrations in private homes	4,800	
Aviation, scheduled carriers (yearly average 1976-1980)	70	

AVERAGE ANNUAL RADIATION DOSES IN THE UNITED STATES

	Millirems
Routine reactor emissions	0.6
Fallout from nuclear bomb tests	4.4
Cosmic rays	28
Natural body radioisotopes	28
Natural isotopes in ground	26
Diagnostic x-rays	70
Average occupational doses for persons working with radiation sources	
Commercial power reactor employee	400
Hospital radionuclide and x-ray worker	350
Dental x-ray worker	125

AIRBORNE RADON STANDARDS (FOR BUILDINGS)

Houses built on Uranium Mine-Wastes in U.S.	Must be below 3 pCi/L	
Phosphate Mining Regions in Florida	4 pCi/L	Take remedial action
	2 pCi/L	Reduce to as low as reasonably feasible
Uranium Mining Regions in Canada	30 pCi/L	Take prompt remedial action
	4 pCi/L	Take remedial action
	2 pCi/L	Investigate
Sweden (maximum levels permitted)	11 pCi/L	existing buildings
	5 pCi/L	houses undergoing remodeling
	2 pCi/L	new houses
Union of Concerned Scientists	Over 5 pCi/L	remedial action indicated
	2-5 pCi/L	remedial action suggested

RADON SOURCES AND PATHWAYS

The *sources* of radon for any home might include:

- Groundwater as it seeps through cracks in bedrock and soil—entering the house through well water.
- Soil gas infiltrating the air of the home.
- Construction materials.

Radon in *well water* may be ingested into the body directly when a person drinks the water or consumes food that contains the water. Or it may affect the body indirectly through passing from the household water into the air that residents of the household breathe. As noted previously, health risks from direct consumption of well water are generally insignificant. It is the air that residents of a house breathe that provides the greatest exposure to radioactivity. And radon can get into the air through water-using activities (as well as through soil-gas and construction materials).

Soil gas is the mixture of gases filling the tiny spaces and pores in the soil. Radon, being a chemically inert gas, can diffuse through cracks in the bedrock or soil particles. The radon decays and dissipates, as it moves; but it may travel far enough to infiltrate into a home and cause elevated levels of radon in the air of the home.

The kinds of soils and rocks that produce high levels of radon in the groundwater can also produce soil gas with high radon concentrations, even if groundwater is not present.

The importance of soil gas as a source of radon in the home is demonstrated by the fact that airborne radon levels have been found to be higher in basements than in other parts of the home. In the 85 homes sampled by UMO researchers, average airborne radon levels were as follows:

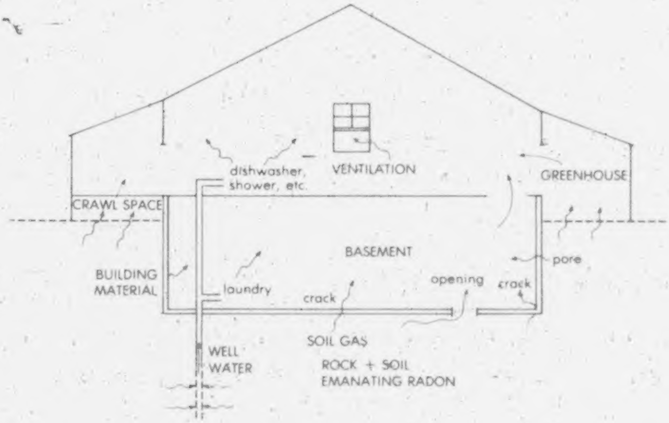
	pCi/L
Basements	6.4
Bathrooms	3.4
Kitchen/Living Rooms	3.1
Bedrooms	3.0
Outside air	0.8

These averages do *not* represent a pattern that is typical or uniform from house to house. Houses with dirt floor basements are particularly exposed to soil gas, and radon levels in such homes affected the averages significantly.

Construction materials have not been found to be important sources of radon in Maine, although further studies may find that concrete may be a significant source of airborne radon in some cases.

With respect to *pathways*, the key factors affecting airborne radon levels in a home include:

- Radon levels in the well water and water-using habits.
- Radon levels in soil gas and type of construction where house and earth meet.
- Ventilation rates of the house.

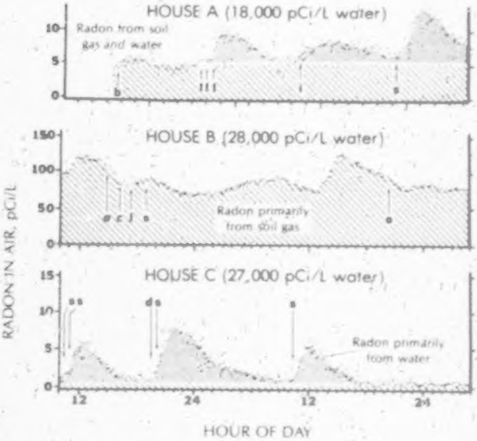


Radon in well water can be released into the air of the home in the course of various water-using activities. The rate at which radon is released from water into the air depends upon the degree to which the water is aerated. When water is agitated, the radon is released as much as eight times faster than when the water is standing and not agitated. Thus, the frequency of use of showers can affect airborne radon levels. Laundry and dishwashing machines can affect airborne radon levels too.

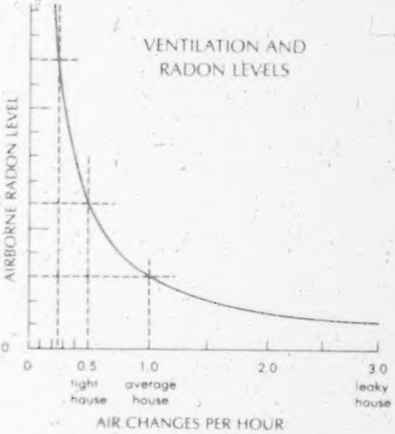
Yet, it should be noted that radon levels in well water do not have a close relationship with airborne radon levels in the home. UMO researchers have placed monitoring devices in bathrooms of a number of houses in order to determine the relationship between waterborne and airborne radon. Some relationship can be seen, but it is not a strong one. It is clear that other factors are involved.

As noted, soil gas is a significant source of radon in some homes. A small amount of such gas entering steadily into a house, if the gas contains radon at levels in the hundreds or thousands of pCi/L, may result in several pCi/L of airborne radon in the house. Such gas can enter basements through dirt floors or cracks and other openings in the basement floor and foundation walls. Thus, the type of structure may be an important factor, especially if the house is an old one. If a house or part of a house is built over a dirt-floor basement or unventilated crawl space, it may be exposed to excessive amounts of radon in soil gas.

PATTERNS OF RADON LEVELS IN THREE DIFFERENT HOMES MONITORED BY UNIVERSITY OF MAINE AT ORONO RESEARCHERS



b = bath, l = laundry, s = shower,
o = open window, c = close window,
d = dishwasher)



The type of structure also affects ventilation, and ventilation is a key factor with respect to airborne radon levels, as the graph above shows. Indeed, there is a direct relationship between air change rates and airborne radon levels. For a given house, a reduction in ventilation rate, say, from one air change per hour to one-half air change per house would double airborne radon levels.

HOUSE A HAD A CONSTANTLY HIGH RADON LEVEL—WITH FLUCTUATIONS THAT CORRESPONDED TO PERIODS OF WATER USE. THE HOUSE WAS TIGHTLY SEALED AND HAD AN OPEN DRAIN IN THE BASEMENT (WITHOUT A TRAP). AIR IN THIS DRAIN HAD AN EXTREMELY HIGH RADON LEVEL, AND THIS AIR APPEARED TO BE DRAWN INTO THE HOUSE BY THE ACTION OF A WOOD FURNACE.

HOUSE B HAD THE HIGHEST AIRBORNE RADON LEVELS OF ANY HOUSE TESTED. (NOTE THE DIFFERENT SCALE ON THE LEFT.) THIS WAS A SOLAR HOUSE WITH ATTACHED GREENHOUSE, THE FOUNDATION OF WHICH WAS SAND AND GRAVEL OVER SOIL WITH GRANITE BEDROCK NOT FAR BELOW. RADON LEVELS WERE SO HIGH IN THIS HOUSE THAT FLUCTUATIONS DUE TO PERIODS OF WATER USE COULD NOT BE DISCERNED.

HOUSE C EXHIBITED THE CHARACTERISTICS OF A HOUSE WHERE AIRBORNE RADON CAME ALMOST ENTIRELY FROM WELL WATER. THE FLUCTUATIONS CORRESPONDED ENTIRELY TO TIMES OF WATER USE, AND RADON LEVELS DIMINISHED TO NEAR ZERO AFTER THE WATER USE.

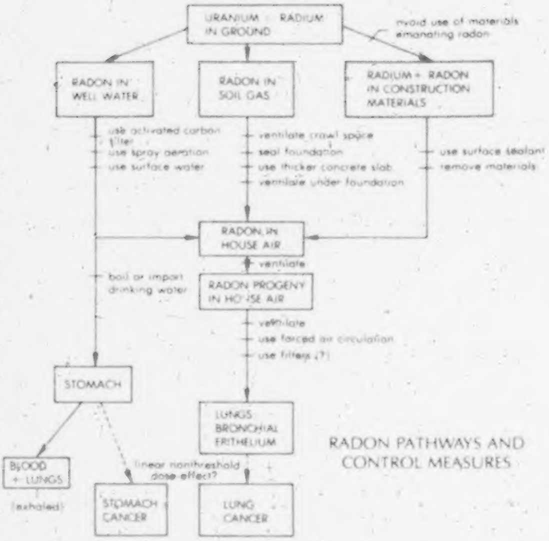
CONTROL MEASURES

The first step a homeowner can take, if he or she is concerned about radon levels in the home, is to have the well water of the home tested for radon. Such a test will not determine directly whether a health hazard exists, but it will indicate whether natural radiation levels are high and whether a *potential* health risk exists, particularly with respect to airborne radon. If radon levels in the well water exceed, say, the 10,000 to 15,000 pCi/L range, the homeowner should consider having the *air* of the house tested for radon.

If radon levels in well water are considerably above the 10,000 to 15,000 pCi/L range, the homeowner may wish to initiate certain control measures, especially those that are easy and inexpensive to take and appear likely to reduce airborne radon sources. If tests for *airborne* radon indicate levels above the various standards listed in the table on page 7 (lower right), the homeowner should also consider control measures that may involve some expense.

Where tests reveal high levels of airborne or waterborne radon, the homeowner will need to estimate:

- the most likely sources of the radon;
- to what extent a particular control measure might reduce radon levels; and
- whether reduced health risks from such control measures seem to justify their cost.


URANIUM + RADIUM IN GROUND
avoid use of materials emanating radon
RADON IN WELL WATER
RADON IN SOIL GAS
RADIUM + RADON IN CONSTRUCTION MATERIALS
use activated carbon filter
use spray aeration
use surface water
ventilate crawl space
seal foundation
use thicker concrete slab
ventilate under foundation
use surface sealant
remove materials
RADON IN HOUSE AIR
ventilate
boil or import drinking water
RADON PROGENY IN HOUSE AIR
ventilate
use forced air circulation
use filters (?)
STOMACH
LUNGS BRONCHIAL EPITHELIUM
BLOOD + LUNGS
(exhaled)
linear nonthreshold dose effect?
STOMACH CANCER
LUNG CANCER

RADON PATHWAYS AND CONTROL MEASURES

Remove Radon from Well Water with Activated Carbon Filter or Spray Aeration System

- Activated carbon filters are available commercially. One can buy a unit that will remove 80-90% of the radon in the water from a relatively low-radon well for around $450. A unit that will reduce 90-99% of the radon from a high-radon well will cost around $800. (These are 1983 prices.)
- The carbon filter unit is similar to a water softener in which the softening compound has been replaced with granular activated carbon. As does a water softener, the carbon filter unit includes an automatic periodic backflushing system to clear accumulated foreign matter from the filter.
- Carbon filters also remove uranium salts, which may be chemically toxic.
- Systems that remove radon from well water through aeration are also available commercially. These systems spray the water inside a large container, which circulates air through the spray and vents the released radon to the outdoors. The cost of an aeration unit is currently (1983) about $2,000 for a removal efficiency of 95-99%. (An improved unit—with 99% removal and somewhat lower cost—is being developed at the University of Maine at Orono.)

Remove Radon from Drinking Water Only

- If all drinking water were to be boiled, left standing open to the air for a few days, or obtained from a source with a low radon content, the radiation dose to the stomach would be virtually eliminated. Radon passes from water to air if the water is boiled or is left standing.
- This approach has the weakness that it focuses on stomach cancer risk, which tends not to be serious, and does nothing to help the problem of airborne radon.
- The benefit, in terms of reduced risk of stomach cancer death, would be on the order of one tenth of a percent less chance of such death for every 10,000 pCi/L reduction in waterborne radon (assuming lifetime consumption). With well water at a 10,000 pCi/L level, the inconvenience might not be judged to be worth the rather small reduction in cancer risk. On the other hand, the effort might be considered worth while if waterborne radon levels were very high and removal of the radon by mechanical unit (such as a filter) were considered too costly.

Ventilate House

- Tightly sealed houses, such as those with solar and energy-efficient designs, may have high levels of airborne radon from radon sources that are relatively low (because of a low air change rate).
- Low rates of air change may increase concentration of other indoor air pollutants as well as radon.
- The ventilation rate of a tight house can be increased significantly by opening a couple of windows a very small amount during the winter.
- The cost of increased ventilation for a whole house may be substantial. If a house were fairly well insulated and had ½ air change per hour, adding another ½ air change would cut airborne radon levels in half—but increase the heating costs.
- The cost could be substantially reduced by ventilating rooms having radon-generating fixtures at certain times. Radon accumulated in a bathroom when released during a shower can be largely prevented from entering the rest of the house by opening the bathroom window before opening the bathroom door—or through use of a ventilating fan.
- The heating cost can also be reduced significantly (by 50% or better) through use of an air-to-air heat exchanger. The units, which range from small window-mounted units to large floor-mounted units, can save up to 70% of the heat in the air exhausted to the outdoors. These units transfer the heat by means of thin metal or paper membranes separating the outgoing warm air from the incoming cold air. These units are reported to pay for themselves within five to ten years.
- Increasing the air-change rate for a house—either by cracking some windows or using an air-to-air heat exchanger—will reduce levels of all indoor air pollutants.

Caulk and Seal a Basement or Ventilate a Crawl Space

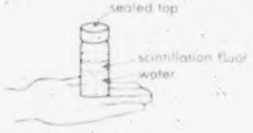
- Due to wind passing over a house and the pull of combustion air for heating or of ventilation air, the air pressure in a basement is normally lower than that in the soil surrounding the foundation. This pressure difference can cause large quantities of soil gas to flow through openings in the foundation.
- Major openings in foundations, like drains or sump-pump holes, are easily recognized, but small cracks and openings in the basement floor and foundation walls can be difficult to detect. A basement radon level two or more times higher than upstairs levels will suggest that such openings are present.
- Untrapped basement drains have been found to be significant sources of radon in some regions. The cost of rerouting a drain or installing a water trap (probably involving some tearing up of concrete and replacement of a few sections of pipe) will vary greatly from one house to the next.
- Epoxy paint or other polymeric coatings in multiple layers can be used to seal porous or cracked basement surfaces. However, roughnesses in the surface should first be caulked and smooth, so that there are no openings the paint cannot fill.
- The cost of sealing basement surfaces can run into thousands of dollars for large buildings. The cost of filling concrete block walls and painting a basement with epoxy would likely be under $1,000 for a typical house. Repainting might be required every ten years or so.
- Adding ventilation to a tightly sealed crawl space (through vents) is not costly, although the resulting heat loss might be. Sheets of polyethelene, polyvinyl chloride, or polamide can be put beneath floors to reduce radon diffusion (and the infiltration of cold air). However, to be effective, there must be no openings or cracks through which the radon can bypass the plastic.

RADON TESTING

In Maine, one can have State authorities measure the radon content of well water for a fee by contacting:

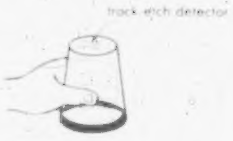
PUBLIC HEALTH LABORATORY
DEPARTMENT OF HUMAN SERVICES
STATE HOUSE STATION 12
AUGUSTA, MAINE 04333
TELEPHONE 289-2727

The lab will send a kit containing a water sample bottle and instructions on how to add water. When the bottles are returned by mail, the Lab injects a sample of the water into a special toluene-based scintillation oil. The lab will measure the radon content and mail back the results. In other states, an inquiry to local or state health authorities will indicate whether a similar service is available.



VIAL FOR WATERBORNE RADON MEASUREMENT

For measuring radon levels in air, one can obtain "track etch" detectors. These are ordinary-looking plastic drinking cups with special strips of a plastic that will detect alpha radiation. A cup is exposed to the air in the main living space of the house for several months (preferably a year), then mailed to a testing laboratory. At the present time, the cups must be obtained and the testing done by a firm in California, but this service may soon be offered by the Maine Public Health Laboratory (see above). Persons interested in testing the radon levels of their air should write or call the Public Health Laboratory.



PLASTIC CUP WITH TRACK ETCH DETECTOR FOR AIRBORNE RADON MEASUREMENT

This digest is based primarily upon the report *Radon, Water, and Air Pollution: Risks and Control*, written by Konrad Weiffenbach, Assistant Professor of Physics, UMO, November, 1982. Readers who wish more complete information than that contained in this digest are referred to Dr. Weiffenbach's report.

UMO faculty members, graduate students, and others who have contributed to on-going studies of radon in Maine include:

Charles T. Hess, Professor Physics
Stephen A. Norton, Professor of Geology
Willem F. Brutsaert, Professor of Civil Engineering
Jerry D. Lowry, Associate Professor of Civil Engineering
Graduate students: Robert E. Casparius, Edward G. Coombs, Jeffrey E. Brandow, Thomas Menerney, and Cindy Moik
Anne L. Hess

The studies have resulted in a number of technical publications, including:

Radon-222 in Potable Water Supplies in Maine: The Geology, Hydrology, and Physics, and Health Effects, Charles T. Hess et al., 1979, and

Investigation of Radon-222, Radium-226, and Uranium in Air and Groundwaters in Maine, Charles T. Hess et al., 1984.

Another report, designed for homeowners interested in obtaining full information on radon removal devices for well water, has recently been completed:

Removal of Radon from Water Using Granular Activated Carbon Adsorption, Jerry D. Lowry, 1983.

These various studies of radon in Maine have been supported with research funds from the UMO Land and Water Resources Center and the U.S. Department of the Interior, the Maine Department of Human Services, and the U.S. Environmental Protection Agency. People who wish to see or have copies of any of the above reports should contact the Land and Water Resources Center, 11 Coburn Hall, University of Maine at Orono, Orono, Maine 04469.

This digest was prepared by Sherman Hasbrouck of the Land and Water Resources Center, UMO, with the assistance of Charles Kittredge and Patricia Wolman, Cooperative Extension Service, UMO. Copies of the digest may be obtained either from the Land and Water Resources Center or from the Division of Health Engineering, Maine Department of Human Services, State House Station 12, Augusta, Maine 04333.

Mr. FUQUA. You mentioned the radon levels, and I know it is in one of the figures in the brochure. You were talking about phosphate mines, and of course we have been very concerned about that in my State and where reclaimed land has been used to build homes. And I think they have determined if they were elevated from the ground level——

Dr. HESS. That is right.

Mr. FUQUA [continued]. And had windows, that that would lessen the impact of radon or other, I guess, pollutants that might cause harm. Is that true in your studies in Maine, where you are talking about building on granite and other types of geological formations?

Dr. HESS. We have houses that have all their radon from water, we have houses where about half of it is from the water and half from the soil, and other houses where it is all from the soil. So in Maine you can get a variety of situations, but I think it is correct that in Florida the radon is coming out of the soil, for the most part.

Mr. FUQUA. What would somebody do if they have it in their water? How—of course, I realize that is related to how many parts per million you may have and the degree of contamination, but are they drinking lethal water?

Dr. HESS. The water can be aerated or can be filtered with carbon filters——

Mr. FUQUA. By city systems?

Dr. HESS. By the city or by the private individual. There is equipment now that can be put on to the water to treat it, to remove this problem.

The—if you have radon in the air of your house due to soil gas, then you have to investigate where it is getting in and what the source is. And that can involve then working on the basement cracks and things like that.

Mr. FUQUA. Well, what would a municipality do to stop the interdiction of radon into their water system? Is there anything they can do?

Dr. HESS. They could add carbon filters or aeration system that will——

Mr. FUQUA. No; that is to get it out. I am talking about to prevent the interdiction of it. Or is it natural?

Dr. HESS. It's natural. It's—the only way you can prevent it is by moving the town.

Mr. FUQUA. That gets rather difficult.

Dr. HESS. Yeah.

Mr. FUQUA. But there are alternative ways, that people are not doomed that just live there.

Dr. HESS. No, it is—I think all of the technology that is needed is already developed to try to cope with this problem. In the State of Maine the human services department has been trying to help people with this, and it is partly the reason why the brochure is shown—they send the people this brochure if they have a high radon reading in either their water or their air.

Mr. FUQUA. Well, what are some of the other health problems associated with radon contamination?

Dr. HESS. As far as I know, lung cancer is the only one that has been shown to be a significant health effect from radon. There is some nasal cancer that occurs in uranium mines as well, but other than—but I think that is a much smaller effect than the lung cancer is. And although you might think that stomach cancer would be a serious possibility, that risks—calculated risks for stomach cancer are much smaller than it would be for lung cancer because that involves the entire exposure from the radon that seeps in from the basement, plus water use and everything together to the lung, whereas the drinking water aspect of it would only be maybe 1 or 2 liters a day to your stomach. So it is a much smaller quantity.

Mr. FUQUA. Dr. Alter, last year when you were here you distributed some things a little different than this one to the members. Did many of them send them back in, and how polluted are we here?

Dr. ALTER. We actually gave the committee one detector for each Member of Congress and one detector to send back home, in the hopes we might get a kind of a scientific participation in the national study. Of those 900 we have received 83 back. That was a year ago. I suspect that most Members of Congress are not scientists and just aren't participating.

However, the air in this room is probably around three-tenths of 1 picocurie per liter. That is about average for office buildings. We do have a mininational survey of about 30 people. As I recall, the highest value was in Butte, Mont., which coincidentally happens to be the site that the EPA is studying the most intensively as far as radon in the homes.

Mr. FUQUA. You didn't find with all these marble and granite buildings here that we were self-destructing then?

Dr. ALTER. Apparently they are very well ventilated.

Mr. FUQUA. That's good.

Dr. Nero, what level of funding did your program request from DOE in fiscal year 1983 for indoor air quality?

Dr. NERO. Well, I should make a distinction between two parts of DOE. In the past, our total funding has arisen from both the Office of Conservation and Renewable Energy at the Department of Energy and from the Office of Energy Research. And, of course, we also get funds from the Environmental Protection Agency and the Consumer Product Safety Commission and others.

If you are referring specifically to the Conservation and Renewable Energy——

Mr. FUQUA. Yes.

Dr. NERO. Part of our budget, that has historically constituted half or more of our total budget and the amount requested from the Department of Energy for the past year was approximately $900,000.

Mr. FUQUA. Now, what tasks were included in that part of the budget, and were they—had they been agreed to by the DOE program managers?

Dr. NERO. There were four major research areas included in that budget. One was study of radon in buildings as it's affected by energy conservation measures, and that included surveys in buildings and study of how radon enters buildings.

A second portion was the study of emissions from building materials into buildings, a variety of materials that emit different kinds of chemicals.

A third part of the funding had to do with control techniques, mainly or at least largely the study of the effectiveness of mechanical ventilation systems with air-to-air heat exchangers and the effectiveness of these devices for providing ventilation while removing indoor pollutants.

And the last was the development of simple passive monitors, about the size of the one that Ward just gave you, for other kinds of pollutants than radon.

The second part of your question as to were these agreed to or discussed with DOE program managers, it depends on which members of the Department of Energy you speak of. The staff program managers——

Mr. FUQUA. Yeah, that is what I was referring to.

Dr. NERO. Have basically agreed to our work on these various areas, and that——

Mr. FUQUA. At the lower working level in DOE?

Dr. NERO. That is right. Yes.

Mr. FUQUA. Could you provide us for the record the funding levels for these various projects that you outlined under this program under the $900,000?

Dr. NERO. Yes.

Mr. FUQUA. You can provide it for the record. You don't have to——

Dr. NERO. It is in the record.

Mr. FUQUA. Oh, OK, good.

Dr. NERO. No, excuse me. It is not in the written testimony. The specific funding levels I would have to provide you separately, yes.

Mr. FUQUA. Certainly.

[The information follows:]

Response of A. V. Nero to Mr. Fuqua's question about funding levels for specific projects for FY83.

The anticipated FY83 funding levels from DOE/CE for indoor air quality research at Lawrence Berkeley Laboratory totaled 900K for experimental work, plus the possibility of 50K (with cofunding from others) for establishment of a computerized data base. The 900K were to be devoted mainly to the four efforts previously mentioned, with the following approximate allocations:

radon	180K
building material emissions	200K
control techniques	235K
passive samplers	215K.

The remainder of the anticipated 900K was to be devoted to a modest effort on combustion appliances (which was cancelled when we were asked to close out the efforts on building material emissions, control techniques, and passive samplers):

combustion appliance emissions 70K.

We proposed that each of these efforts continue into FY84, in each case investigating new areas, and that we add two new efforts:

concentrations of indoor pollutants data base (already mentioned as receiving possible funding for FY83) - collecting existing data into a computerized system with cofunding from other entities;

survey design - lending DOE support to design of surveys that could help delineate the relationship between indoor pollutant concentrations and building-related factors.

Mr. **Fuqua**. Now, was this work consistent with the buildings energy research sponsored by our committee and DOE in January of 1983?

Dr. **Nero**. When you say "consistent with," you mean did it follow the expectations?

Mr. **Fuqua**. Yes, yes.

Dr. **Nero**. Yes.

Mr. **Fuqua**. Complement or correspond to what we requested?

Dr. **Nero**. Yes; it fitted quite well with the expectations for your funding.

Mr. **Fuqua**. Well, now, were any of these duplicative of work being carried out by the private sector or any other parts of the Government, say some of the other national labs or any ones that you were aware of?

Dr. **Nero**. Some of this work is in areas in which other people are doing research, but as typically happens in a scientific research effort, the efforts are not duplicative. They tend to be complementary. And these were directed more specifically than other research being carried on to the relationship between indoor air quality and energy conservation and, in addition, techniques that could be used for defining that problem.

So the answer is no, it was not duplicative. In many cases it was comple—there was other work taking place that was complementary.

Mr. **Fuqua**. Well, were they actually requested or were the tasks that you requested, were they actually funded by the DOE conservation?

Dr. **Nero**. Do you mean in the end or with the expectation of——

Mr. **Fuqua**. With the expectation.

Dr. **Nero**. We had the expectation of funding for work in all of these areas that I just mentioned.

Mr. **Fuqua**. And then were they funded?

Dr. **Nero**. They have not been fully funded.

Mr. **Fuqua**. Have they been partially funded?

Dr. **Nero**. They have been partially funded; that is to say——

Mr. **Fuqua**. How much is "partially"?

Dr. **Nero**. You will excuse me if I can't answer the number precisely because it takes place in the context of a much larger program at Lawrence Berkeley Laboratory on energy conservation. But basically the situation is the following: that three of the areas that I mentioned are due for close-out, three of the four——

Mr. **Fuqua**. By your choice or DOE?

Dr. **Nero**. That's DOE's decision.

Mr. **Fuqua**. Who made that decision?

Dr. **Nero**. The decision was made jointly by, if I understand correctly, the leadership of the Office of Conservation and Renewable Energy, including—well, you will have to ask—I assume that Assistant Secretary Tribble will be testifying tomorrow, but it was basically his immediate staff.

Mr. **Fuqua**. Well, was it Mr. Tribble that made the decision?

Dr. **Nero**. Well, it was he or his immediate staff.

Mr. **Fuqua**. Who is "immediate staff"? His principal assistant or was it made by Tribble?

Dr. **Nero**. Well, ultimately the decision, of course, was made by Mr. Tribble.

Mr. **Fuqua**. But the other people down the line had approved it in the more working level?

Dr. **Nero**. They had——

Mr. **Fuqua**. You answered that affirmatively a few minutes ago.

Dr. **Nero**. Yes; that is right.

Mr. **Fuqua**. So when it got to Mr. Tribble, then it was rejected?

Dr. **Nero**. Well, as you might expect, I cannot be privy to the particulars of how this happens——

Mr. **Fuqua**. I understand. I understand.

Dr. **Nero**. But basically, it was——

Mr. **Fuqua**. But tentative approval had been granted at a lower working level?

Dr. **Nero**. Yes.

Mr. **Fuqua**. And when it reached the Assistant Secretary that has responsibilities in this field, for some reason it was denied?

Dr. **Nero**. That is correct.

Mr. **Fuqua**. When was that decision not to fund those made? Was it—on the project? Was it made late in the fiscal year or early?

Dr. **Nero**. We first received indications of this in May, which is during the second half of the fiscal year, and our first formal indication was received in June of this year, so it was very late in the fiscal year.

Mr. **Fuqua**. So the notification that you had about disapproval first surfaced in May and then was finalized in June of fiscal year 1983.

Dr. **Nero**. It really first surfaced in June. There were suggestions that that was going to happen in May.

Mr. **Fuqua**. In May.

Dr. **Nero**. Yes.

Mr. **Fuqua**. Now, what impact did this have on your programs after you had already started and was half through the fiscal year, approximately half through.

Dr. **Nero**. The—as you might expect, we had been proceeding on these various research areas until that time on the presumption that our basic understanding would be followed through. So that the impact is a—in large part a fiscal one in terms of trying to understand well, where does the support for the work that actually occurred come from and second, what happens to the programs that we had undertaken both in this fiscal year and in the future.

That, of course, is a question that has caused us a great deal of difficulty, as you might expect. So that our staff presently still is there. We are working, generally speaking, in these same areas. We are closing out several of them on the presumption, as indicated to us from the Department of Energy, that the work would not be continued in those areas.

Mr. **Fuqua**. And what are your plans for fiscal year 1984?

Dr. **Nero**. The plans for fiscal year 1984, as you might imagine, are highly uncertain in respect to the kinds of work that we have been doing for Conservation and Renewable Energy. There is some indication that they will continue some of the radon-related work, but as I've indicated, they have expressed the desire that the other work be closed out. There has been an invitation to propose new work, but there is no indication of acceptance of that work. So we face the prospect of a very large change in our program and a great deal of uncertainty.

Mr. **Fuqua**. Well, now, is it possible to know the magnitude of the potential problem of indoor air quality without a national survey, such as the one that you were proposing to the DOE?

Dr. **Nero**. I think that there is general agreement within the research community and others that such a survey is absolutely necessary to characterize exposures of the population and the distribution of those exposure sizes to a wide variety of pollutants, so that work of that kind is certainly necessary.

Mr. **Fuqua**. But under the proposed funding of DOE, then that survey would not be possible?

Dr. **Nero**. The—it's clear that such a survey has to be undertaken as a joint responsibility of the several agencies because of the different capabilities and interests, and without the Department of Energy's participation in that the whole question of how indoor pollutant levels are related to building-related factors, such as ventilation rates, would not be able to be explored effectively.

Mr. **Fuqua**. Thank you.

Mr. MacKay.

Mr. **MacKay**. Mr. Chairman, I formerly served as a chairman of a phosphate reclamation policy study group in Florida, and they were very much concerned about radon and the number of subdivisions that are being built on reclaimed phosphate lands.

And one of their problems was that there was supposedly a study going to be funded but it never seemed to be able to be funded. I am not sure that it has been even yet. Apparently the problem in Florida is that the tailings from phosphate mines and also the gypsum piles, which is a waste product, emit radon gas in fairly high concentrations.

I noticed, Dr. Alter and Dr. Hess, both of you referred to Florida. And I wonder what studies there were and what advice you would have, since it is practically impossible to get advice in the State of Florida about this, what advice you would have about the State continuing to allow homes to be built in these areas.

Dr. **Alter**. If I may respond briefly, and I think Tom will probably do so, too.

The phosphate problem, as you know, is—there are two parts. No. 1, there are houses which are just built. They happen to be built over phosphate rock, which is unmined. There are also buildings built over reclaimed phosphate mines and near gypsum tailings piles, which, as you know, contain most of the radium from the phosphate.

We have worked in Florida largely with industrial clients concerned with processing of phosphates where there are radon and radium levels. We have heard of attempts to do a little bit more research in that area, but I think you are correct, they have not really come about. We are going to be talking with some of the people at the university about research like that.

One of the nice things about Florida is that it is not very expensive to throw open the windows in the wintertime. And so you may have a fairly high source, but you may have very good ventilation.

Dr. **Hess**. I would think that the Florida problem could be dealt with in the same fashion as other States; that is, as a geological source problem and could be researched and investigated to find out where the areas are and then the determination can be made based on knowledge of how many houses have the problem. Right now it seems to be that the problem has been associated largely with the tailings piles and not very much with natural radon from say unmined rock.

Whether or not that problem extends over other parts of Florida, I don't know. Perhaps one of the people that is doing research down there in Florida could better answer your question about that.

But I would think that combined with the geologists and with the survey, you could find out where the problems are in Florida and then if the problems are really extensive, you could have some special consideration about housing built on those areas.

Mr. **MacKay**. Does the radon in the water—could we—can we assume that in areas where there is a high concentration of phosphate rock and the aquifer is basically running in or under that, or else the water is filtering through that, that there is high radon concentration in the water?

Dr. Hess. I think I have seen data from Florida. I could show you the average values from Florida. This slide shows the average values of radon in water in each of the States where the information is available, and it is the result of measurements in public ground water supplies. That would mean these are all utility supplies. So you can get some idea of how Florida water would be compared, say, to the water in New England.

You can see that the average there is 30 picocuries per liter. That's one of the lower values that you will find on that chart. And high values for an average of utility supplies would be over 2,000, such as you would find in Rhode Island or Maine, 999 for Maine; Virginia is 350; but Florida comes out to be 30. So I would say judging from the utility water, the water supplies in Florida would tend to be low in radon.

Private supplies, however, tend to be quite a bit higher than public supplies because public supplies have to be taken out of aquifers that are very plentiful, so that you can get large amounts of water. And the radon tends to be lower there than it does in private wells.

Mr. MacKay. The brochure that is attached to your written testimony, how was it—how was this research and development effort funded?

Dr. Hess. Most of the work that is shown in the brochure was either funded by the USEPA or by the U.S. Department of Interior under the Water Research and—it's called the Office of Water Research and Technology, a subset of the U.S. Department of Interior.

And the focus of this research came from the Clean Drinking Water Act that specified that carcinogens in drinking water should be studied. And it was the result of that—that resulted in money being appropriated eventually so that these kinds of things could be studied.

Two or three grants occurred from 1972 to 1978, and eventually a large report was written sort of summarizing all of the results and then from that large report the small brochure was condensed, so that we could have something to give to people when they ask questions. And it has been used as a—to answer questions that we get whenever radon becomes a question in Maine, and they write to us.

Mr. MacKay. I was interested in the comment, Dr. Alter, that in Florida fortunately you could just raise your windows in the wintertime. To what extent do you think or have you made any study to know the extent to which people are aware of the problem? It seems to me that utilities and other people are spending huge amounts of money which shows up again in the rate structure to convince people not to open their windows, but in fact to seal their windows.

I am asking if you think there is any responsibility for Government at least to let people be aware that they might have a problem which they are making worse, which I think is the basic thrust of what you are saying.

In other words, what is your estimate of the severity of risk as compared to the Government expenditures for research and dissemination of knowledge?

Dr. **Alter**. Well, as I pointed out in the first chart, the severity of the exposure and presumably, therefore, the risk is the greatest for radon decay products, greater than any other source either natural or artificial, and yet it seems to me that the spending for research is not commensurate with the risk. I am not saying that spending on research to protect us from other kinds of radiation isn't a very good thing. I am just saying that the spending is not commensurate with the risk.

The problem with the energy conservation activity and—is that you can almost calculate the excess cancers that could result in the general population by, for example, a decrease in the air change rate by say 50 percent.

That's an extraordinarily simple calculation to make with EPA risk estimates. I think the EPA itself a couple of years ago estimated that there might be as a result of wide scale conservation activities something like 200,000 excess lung cancer deaths. That is fairly old knowledge, but the facts are still the same as they were 2 years ago.

The conservation measures in the Southern part of the country are, of course, directed mainly at hot weather, where you don't want to waste your air conditioning dollar and you have to keep the house tight and keep that hot air from coming in. It is kind of the reverse.

And we would expect, therefore, that indoor air quality would go down in the summertime in the South and be a lot better in the wintertime; just the reverse in the North.

Mr. **MacKay**. I am not sure whether this information has been provided. If it has, I don't want to duplicate. But do you have information or is it possible to get information for the record of this hearing on the number of deaths or health problems associated with radon contamination?

Dr. **Nero**. Could I comment on that, if you don't mind?

Mr. **MacKay**. Yes, sir.

Dr. **Nero**. There is a fair amount—there has been a fair amount of work done on trying to estimate the total risk from exposure to radon progeny indoors. For example, there is a special issue of the Journal of Health Physics, which is coming out this month, that is devoted entirely to the question of indoor radon and that has several articles on the question of risk.

Now one thing, though, that is important to realize is that, just as an example, the estimates that Ward just cited from the Environmental Protection Agency, within the radiobiological community it's generally felt that those risk estimates were much too tight; that is, that the uncertainty in the risk is much larger than indicated. It is still at a level where one can say reasonably that there's an expectation of some thousands of lung cancer deaths per year among the U.S. population from the current levels of exposure.

One clarification of the EPA comments should be made, though; that is, as Ward is aware, the EPA made estimates of what the impact of energy conservation measures would be on these exposures and as has been made clear from the reaction from the scientific community to those estimates, they made some rather gross assumptions about what impact energy conservation would have.

So that one should be a little careful in making those estimates, and I would refer you, for example, to the discussion in some of the articles in that journal that I just mentioned.

One of the important things, though, that we should be aware of, aside from making estimates of the risk, is that the risk varies tremendously within the U.S. housing stock, as I indicated before, ranging from concentrations that are low enough to be of no real concern to concentrations that are so high that none of us sitting at this table would be willing to live in a house unless something was done about it.

And that a substantial research effort is required to try to, in a systematic way, identify those portions of those country or those portions of the housing stock that suffer from these unusually high concentrations.

And second, although for some situations it is pretty clear how to reduce the high concentrations, that is not clear in general. So that a good deal of work has to be done to understand how radon enters buildings and how effective various approaches to reducing that entry rate might be.

It's not enough to simply know what the level is. It requires a fair amount of work and understanding how the radon gets in and, as I say, how effective a particular measure might be in controlling it. And frankly, that is not understood at the present time for many routes of entry into houses.

Mr. MacKay. My recollection of some of the testimony in the phosphate study that we were doing a few years ago in Florida was that in fact some of the material that was being incorporated into the houses used to build concrete block or brick was also a source of radon and that no unit of government seemed to feel any responsibility to point that out.

Dr. Nero. I think it is—excuse me, Tom. I think it is fair to say that many units of government are aware of the problem and realize that they could contribute to a solution of the problem, but the difficulty, as has been made clear, is that many of these agencies do not have clear responsibilities in this area.

Some, in spite of that, have been doing a fair amount of research, and that includes the Department of Energy, the Environmental Protection Agency and others. It would be of benefit to define those responsibilities or charge the agencies with more specific responsibilities.

Dr. Hess. I would like to reply to your question previous, one question previous about the risk estimate. I have recently calculated risk estimates for the State of Maine to see county-by-county what the risk would be from drinking water with radon in it. I calculated for the whole State about 88 per year. The highest county was 20 and the lowest county was less than 1 per year, lung cancers from the radon in the water.

A similar kind of thing can be done for radon in air. After you have measurements for each county, you could tell people exactly what the risk is in a particular county. That should be done for the whole United States, for every State, so that we know just what the risk is.

Right now, I would be hard-pressed to come up with a good estimate in a State where they haven't measured very many samples.

And so the kinds of numbers that we are talking about are national averages based on the samples measured so far, and as the time goes by and more samples are added, the numbers are going to change some.

But most of the calculations yield numbers like of the order of 10,000 to 20,000 people a year or, at the other end, perhaps 1,000 to 2,000 people per year. So we have something that has a very large range on it because the studies haven't been done State-by-State to find out what is going on. We know a lot more about Maine water and air than could be said about Indiana, see, or other States.

So that is why the statements are rough. It is not because the science is necessarily bad science. It is because we don't have the input information to make it more precise.

Mr. MacKay. I understand, so if you could get a better sample you could be much more definitive as to the risk?

Dr. Hess. Exactly. It seems to me, though, that the—pinning this number down very precisely may not be the real issue. It may be begging the issue. The issue is that we know about how many people are harmed by it—it is a substantial number—and is it right to wait until all the data is in and we can tell you exactly, when you live in a certain town, what the risk is of living in that town when all of that time you could have been doing something about ameliorating the problem, perhaps making some changes that would have avoided those numbers initially. I mean——

Mr. MacKay. So what we need to do is find out whether your chances of death outside from acid rain, of which we don't have enough information for government to take action, are greater than your risk of staying inside to get out of acid rain, about which we also don't know enough because of——

Dr. Hess. I agree with you. There is a problem there.

Mr. MacKay. Do you feel that appropriately there should be Federal standards? It would appear to me that efforts at State and local levels are necessarily going to be handicapped unless there are some Federal standards. There are work standards, as I understand it, because of OSHA. Is that correct?

Dr. Hess. That is correct. I think that having a standard is not going to necessarily be the whole solution. A standard is something that should come at the end of the measurements because if you—the standards should be based on a knowledge of what the problem is, not on trying to—if you set a standard first and then go and do the measurements, you are going to be like Sweden. They did a few measurements, set a standard, and then they found a vast number of houses that exceeded the standard. Then they are in the position of, well, is this standard too strict.

And I think that is a bad way to do it. I think the right way to do it is to do measurements—some more measurements to find out better what is going on and then set a standard as the last step in the process, after better information is known.

At the same time, I feel that it isn't right to just wait until sort of this data generally accumulates because other people do it as part of other projects and so on and hopefully someday get a number that is an accurate number. It seems that focused work needs to be done to get the answers soon because it is a pressing problem that may involve thousands of lives. And so for that reason rough numbers are needed right away and then more precise numbers over a period of time.

Mr. MacKay. Of course, there are a number of people who fear what they call a level of hysteria, which means that they may not be able to sell their property if people really understand the risk involved, and they may not be able to mine their property or reclaim their property.

I gather that I have the honor of adjourning this meeting. I am sorry, Congressman Lowery just came in, and he may have some questions.

Congressman Lowery, do you have any questions? I was sort of left to sort of wind things up?

Mr. Lowery. I do.

Did you do any research in the area of manufactured housing as it relates to formaldehyde?

Dr. Nero. If I may comment on that, there are a number of groups in the research community who are doing such research. We have done a modest amount at Lawrence Berkeley Laboratory, and generally speaking, based not only on our data but on other people's data, it's fairly clear that manufactured housing has a tendency to use certain kinds of products that do have pretty significant emission rates of formaldehyde, and furthermore, that that housing is on the tight side of the housing stock, so that one can get fairly significant—higher concentrations in manufactured housing than in the general housing stock.

Mr. Lowery. To the point where it is hazardous to one's health?

Dr. Nero. To the point where it is in the range that there is a significant potential. Unfortunately, as for many of these pollutants, it isn't clear exactly where you can get what particular health effect. But it is clear that in a certain fraction—in a large fraction of manufactured housing you get higher concentrations than average and that in a significant fraction you get concentrations that are of substantial health concern.

Mr. Lowery. Partly because there is less ventilation, because it is such a closed environment?

Dr. Nero. And largely because of the materials used in the building; yes.

Mr. Lowery. Do we have any idea on a time line as to when we will know what various health impacts are, let's say of radon or formaldehyde and manufactured housing, for instance?

Dr. Nero. Well, there are other people here who can address that and people tomorrow will be addressing that specifically. But the general time line on understanding these health effects is that we understand a fair amount now and that as time goes by we will understand more. I think——

Mr. Lowery. How much time?

Dr. Nero. Well, for an indefinite period we will understand more, but the question is when will we understand enough to do something about it, I believe. And certainly we know enough about it now to be undertaking substantial efforts to characterize what exposures are and to undertake research efforts that better define what the health effects are, so that a couple of years down the line we will have much more substantial information, so that we are talking about—we know enough now to start doing things and within a couple of years we will know enough to start doing more. It is not a question that is going to extend for several decades from now.

Mr. **Lowery**. Thank you very much.

Mr. **MacKay**. Gentlemen, I very much appreciate your participation. It has been very helpful to us. We will adjourn this hearing, and we will begin again tomorrow.

Thank you very much.

[Whereupon, at 12:25 p.m., the subcommittee adjourned, to reconvene at 9:30 a.m., Wednesday, August 3, 1983.]

INDOOR AIR QUALITY RESEARCH

WEDNESDAY, AUGUST 3, 1983

U.S. HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS, AND SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH, AND ENVIRONMENT

Washington, D.C.

The subcommittees met in joint session, pursuant to call, at 9:30 a.m., in room 2318, Rayburn House Office Building, Hon. Don Fuqua (chairman of the Subcommittee on Energy Development and Applications) presiding.

Mr. **FUQUA**. The hearing will be in order.

Our first panel this morning will be the Health Effects of Indoor Pollution, and our first witness will be Dr. James Melius, Chief of Hazard Evaluation and Technical Assistance Branch, of the National Institute for Occupational Safety and Health, and Dr. Jan Stolwijk, chairman of the Department of Epidemiology and Public Health, Yale University School of Medicine.

Dr. Melius, we will begin with you this morning.

[The biographical sketch of Dr. Melius follows:]

BIOGRAPHICAL SKETCH

James Malcolm Melius, M.D., Chief, Hazard Evaluations and Technical Assistance Branch, National Institute for Occupational Safety and Health (NIOSH)

Dr. Melius was born in 1948, in Gt. Barrington, Massachusetts, and grew up in Copake Falls, New York. He attended Brown University, Providence, Rhode Island, receiving his A.B. in Biology in 1970 and a Master of Medical Science in 1972. He completed medical school at the University of Illinois College of Medicine, Chicago, Illinois, receiving his M.D. in 1974. He spent the next three years as a Family Practice Resident at West Suburban Hospital, Oak Park, Illinois (Board Certified in Family Practice in 1977). For the next three years, Dr. Melius was a student and faculty member at the University of Illinois School of Public Health while working on a doctoral degree in epidemiology. (He will receive his Dr.P.H. in epidemiology in August 1983.) While at the School of Public Health, he also spent a year in the Affiliated Occupational Medicine Residency Program at Cook County Hospital, Chicago, Illinois. He was certified in Occupational Medicine by the American Board of Preventive Medicine in May 1979. While at the School of Public Health, Dr. Melius conducted research in occupational medicine, environmental epidemiology, and cancer epidemiology.

In January 1980, Dr. Melius began work at the National Institute for Occupational Safety and Health as the Chief of the Hazard Evaluations and Technical Assistance Branch. He currently supervises a professional staff of approximately 50 industrial hygienists, physicians, and other occupational health personnel who conduct approximately 500 occupational health hazard evaluations each year. These evaluations, covering a wide variety of occupational health problems, are conducted at the request of employers, employees or their unions, or other governmental agencies. While at NIOSH, Dr. Melius has published several papers on occupational health problems. In 1981, he received the Public Health Service Award for Superior Work Performance.

Dr. Melius currently lives in Cincinnati with his wife and two children.

STATEMENTS OF JAMES MELIUS, M.D., CHIEF, HAZARD EVALUATIONS AND TECHNICAL ASSISTANCE BRANCH, NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH, CENTERS FOR DISEASE CONTROL; AND JAN A. J. STOLWIJK, PROFESSOR OF EPIDEMIOLOGY AND PUBLIC HEALTH AND CHAIRMAN, DEPARTMENT OF EPIDEMIOLOGY AND PUBLIC HEALTH, YALE UNIVERSITY SCHOOL OF MEDICINE, AND ASSOCIATE DIRECTOR, JOHN B. PIERCE LABORATORY, NEW HAVEN, CONN.

Dr. MELIUS. Good morning. My name is Dr. James Melius. I am Chief of the Hazard Evaluations and Technical Assistance Branch of the National Institute of Occupational Safety and Health, Centers for Disease Control. I am happy to be here today to testify on current investigations and research on indoor air quality being conducted by NIOSH and by the Center for Environmental Health of the Centers for Disease Control.

I would like to summarize my full written testimony here to save time——

Mr. FUQUA. Yes; we will—that will be certainly agreeable and we will make your prepared statement a part of the record.

Dr. MELIUS. Fine, thank you.

Both NIOSH and CEH, Centers for Environmental Health, respond to requests for assistance to deal with problems arising out of indoor air pollution, both in the workplace and in home environment. Centers for Environmental Health usually respond by giving assistance through State and local health departments.

Most of NIOSH's investigations are done through the hazard evaluation and technical assistance program. Under this national program, NIOSH responds to requests for evaluation of occupational health problems from employers, employees, or their unions, or other governmental agencies.

Since 1971, NIOSH has conducted over 200 indoor air quality investigations, nearly all of these within the last 5 years. Nearly all were conducted in response to worker symptoms or illnesses which were thought to be related to the building environment which the people were working.

I would now like to summarize several categories, major categories, which we have found of these 200 investigations.

First is contamination from outside the building. In some instances, we have traced the source of the complaints to contamination from outside the building. Occasionally, this can be quite unusual or dramatic, such as a recent investigation which complaints of eye irritation and headaches among workers in a medical office led to our discovery of a large underground gasoline leak which was seeping into the basement and stairwells of that building. More often, the source of outside contaminants is more obvious, such as exhaust from an adjoining motor vehicle garage, construction site, or powerplants.

The second category is contamination from building materials. In these evaluations, we find evidence of contamination from materials used to construct the building, such as fibrous glass insulation, carpet adhesive, or urea formaldehyde foam insulation. A related problem is contamination from deteriorating asbestos insulation used in many buildings constructed particularly in the fifties and sixties, a major problem in many of these buildings and one for which we are often asked to provide assistance and give advice.

The third category would be contamination from copying machines and other office machinery. In these we are usually asked to evaluate symptoms caused by exposure to contaminants from photocopiers, spirit duplicators, and similar office machines. In these investigations, we usually evaluate exposure to specific chemicals which may be released by these machines, and symptoms experienced in relationship to these specific chemicals.

The fourth category is hypersensitivity pneumonitis. Over the past 3 years we have conducted 10 investigations of hypersensitivity pneumonitis among office building employees. Hypersensitivity pneumonitis is a flu-like illness characterized by episodes of fever, chills, malaise, muscle aches, and usually chest tightness. Symptoms usually improve after the workers leave the building for vacations or weekends, only to recur when they return to the work environment. The cause of the illness is an immunological sensitization to microorganisms in the building environment. However, detection of specific microorganisms associated with an outbreak is often quite difficult. Environmental evaluation of these buildings is quite complex due to the variety of organisms which may be associated with the disease, the intermittent nature of some of the outbreaks, and our lack of knowledge about the health effects of microbial contamination of building environments and the lack of appropriate guidelines for controlling these outbreaks.

NIOSH has recently conducted considerable research toward the development of better methods for assessing contamination in these work environments. However, control of the contamination problems in buildings where outbreaks have occurred has been quite difficult.

The fifth area would be contamination from chemicals used in building maintenance. By this I mean exposure to things such as carpet cleaning agents, agents added to the building's humidification system, or pesticides which may be used in the building.

Finally, inadequate ventilation. In over half of our indoor air quality investigations we found the major cause of the problem to be inadequate ventilation of the building. The symptoms experienced by office workers in these buildings are usually nonspecific, but notably similar from building to building, including headache, eye, nose, and throat irritation, fatigue, and in some cases, dizziness and nausea. The symptoms experienced by many of these workers are severe enough to result in lost work time, reassignment, or even termination of work. Although complaints usually originate in one area of a building, questionnaire surveys of the building occupants usually reveal that the symptoms are widespread, affecting both professional and nonprofessional workers.

Because of the highly emotional nature of many of these situations, the complexity of the buildings, and the fact that environmental monitoring may be inconclusive, the results of the investigations are often quite difficult to interpret.

Although more serious illnesses such as cancer, heart attacks, are occasionally attributed to working in these building environments, no clear evidence of health problems more serious than apparent allergic reactions in a few individuals to specific office contaminants has been found. However, our studies have not addressed the question of whether there are long-term health effects associated with working in these environments. Nearly all of them have been short term and have been limited to a particular office environment.

In these situations, we have usually concluded that, based on low levels of contaminants found in our environmental monitoring, and the widespread reporting of nonspecific symptoms, that the cause of the problems is inadequate building ventilation. Often, for energy conservation reasons, the amount of fresh air being introduced has been limited or in some cases almost no provisions have been made for introducing fresh air into the building. Seasonal cooling or heating requirements often lead to intermittent reductions of fresh air through the building ventilation system, and the design of the building or modifications made to the building after construction may also interfere with the distribution of fresh air into certain work areas.

Although only low levels of specific contaminants may be identified by the current means for environmental monitoring, we believe that the cause of symptoms in these buildings is the buildup of low levels of natural building contaminants, such as off gasing from building materials and emissions from office machinery.

Inadequate ventilation does not provide for the means for exhausting these contaminants. Undoubtedly, cigarette smoke plays a role in increasing the contamination of the office air and in producing symptoms among both smokers and exposed nonsmokers.

Unfortunately, we have not been able to identify a specific chemical contaminant, the concentration of which would allow us to say that more ventilation is needed for these buildings. For evaluating the adequacy of building ventilation, we usually use the ASHRAE guidelines, which I believe were discussed at length at yesterday's hearings. However, I would like to point out there has not been a systematic study to demonstrate that following these ventilation guidelines will prevent the development of the type of symptoms reported in our investigation.

Nevertheless, we usually cite these standards in our reports as a guide for improving the ventilation in buildings where we found this type of problem.

Thus far in my testimony I have described CDC research and investigations related exclusively to indoor air pollution in the workplace. We have also intitiated programs that include nonoccupational exposures to indoor air pollution.

As a part of this effort, in 1982, CDC's Center for Environmental Health conducted a survey of State health department programs for hazard evaluations of nonoccupational indoor air pollution. The survey included questions regarding the type of State programs established to deal with this problem and a section on State evaluation of complaints related to presumed exposure to formaldehyde.

Survey results you may find interesting include that, of the 50 States and District of Columbia, 32 have a specific program or persons responsible for nonoccupational indoor air pollution; 28 can evaluate formaldehyde exposures; and 47, 92 percent, have no existing proposed nonoccupational indoor air pollution standards. The results underscore the wide range of State capabilities in this area, and the diverse programmatic responses to a commonly occurring exposure hazard such as formaldehyde. The identification of the responsible program components for these activities within each State health department gives us a valuable list of contacts with whom we can exchange technical information and guidance.

In response to your request for suggestions for further research on indoor air quality, I would like to outline three major, interrelated areas:

First, we need better means to assess indoor air quality and identify indoor air hazards. We have done considerable work at NIOSH in assessing chemical and microbial contamination in problem buildings, but we do not believe that adequate methods are yet available. For buildings where we attribute the problem to inadequate ventilation, contaminants responsible for causing symptoms in exposed workers need to be identified and appropriate methods developed for their assessment and control.

Second, epidemiological studies. Careful epidemiological and medical studies need to be done in buildings to determine the prevalence and incidence of symptoms and other medical conditions in relation to the building environment. Careful followup environmental and epidemiological studies need to be done to determine to what extent corrective actions have actually improved the health of building occupants and to determine what, if any, long-term health effects there may be. Such studies could provide the basis for better guidelines for controlling these problems.

Third, control methods. Research needs to be done to determine how changes in a building ventilation system may affect exposures to building contaminants such as asbestos or microorganisms. Research is also needed to develop better methods for controlling exposures to other office contaminants at their sources.

Thank you for the opportunity to describe our indoor air quality work, and I would be happy to take questions, I believe after the next speaker.

[The prepared statement of Dr. Melius follows:]

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
Atlanta, Georgia 30333

TESTIMONY OF

JAMES MELIUS, M.D.
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
CENTERS FOR DISEASE CONTROL
PUBLIC HEALTH SERVICE
DEPARTMENT OF HEALTH AND HUMAN SERVICES

Before

Subcommittee on Energy Development
and Applications

Subcommittee on Natural Resources, Agriculture
Research, and Environment

United States House of Representatives

August 3, 1983

Good morning.

My name is Dr. James Melius, Chief, Hazard Evaluations and Technical Assistance Branch, National Institute for Occupational Safety and Health (NIOSH), of the Centers for Disease Control (CDC). I am happy today to testify on current investigations and research on indoor air quality being conducted by NIOSH and by the Center for Environmental Health (CEH) of the Centers for Disease Control.

The Center for Environmental Health was established in the Centers for Disease Control to implement environmental public health programs for a wide variety of problems. During the past several years, CEH has upon request, provided -- primarily to State and local health departments -- epidemiologic assistance or technical advice on specific indoor air pollution problems.

As you know, the National Institute for Occupational Safety and Health was established to conduct research in occupational health and safety; to develop criteria for safety hazards and occupational exposures to physical, chemical, and biological agents; to recommend these criteria to the Department of Labor for consideration in setting standards; and to train occupational safety and health professionals.

Most of NIOSH's research on indoor air quality has been done as part of the Health Hazard Evaluation and Technical Assistance Program. Under this national program, mandated by the Occupational Safety and Health Act and the

Mine Safety and Health Act, NIOSH responds to requests for evaluation of occupational health problems from employers, employees or their unions, and other governmental agencies. After receiving a request, NIOSH investigators visit the workplace and may then collect appropriate industrial hygiene samples, evaluate the ventilation system, and conduct medical examinations or an epidemiological study, as necessary, to evaluate the extent of any occupational health problem in that facility. At the completion of each investigation, a publicly available report is issued to the requestors and other involved parties. The report includes the study findings and recommendations to correct specific occupational health problems in that workplace.

Since 1971, NIOSH has conducted over 200 indoor air quality investigations. More than 90 percent of these investigations were conducted in the last five years. Nearly all were conducted in response to worker symptoms or illnesses which were thought to be related to the building environment in which the people were working. Generally, that the indoor air pollution evaluations that we have conducted are categorized by the source of contamination in the environment--if we can identify it--or, otherwise, by the type of symptoms or illnesses experienced by the workers. I will briefly explain some of these categories.

1. Contamination from Outside the Building: In some instances, we have traced the source of the complaints to contamination from outside the building. Occasionally, this outside source can be quite unusual, as in a

recent investigation in which complaints of eye irritation and headaches among workers in a medical office led to our discovery of a large underground gasoline leak which was seeping into the basement and stairwells of the building. More often, the source of outside contaminants is more obvious, such as exhaust from an adjoining motor vehicle garage, construction site, or power plant.

2. Contamination from the Building Materials: In these evaluations, we find evidence of contamination from materials used to construct the building, such as fibrous glass insulation, carpet adhesive, or urea formaldehyde foam insulation. The health complaints are usually specific to a causative agent (dermatitis from fibrous glass, eye and upper respiratory irritation from formaldehyde). A related problem is contamination from deteriorating asbestos insulation used in many buildings constructed in the 1950's and 60's, a major problem in many buildings and one for which we are often asked to give advice and provide assistance.

3. Contamination from Copying Machines; In many instances, we have been asked to evaluate symptoms caused by exposure to contaminants from photocopiers, spirit duplicators, and similar office printing machines. In these investigations, we have evaluated exposure to specific chemicals which may be released by these machines (such as methyl alcohol from spirit duplicators, ozone or trinitrofluorenone from copying machines, and

methacrylates from signature machines). The symptoms experienced by office workers using these machines are usually specific to the chemicals being released.

4. Hypersensitivity Pneumonitis: Over the past 3 years, we have conducted 10 investigations of hypersensitivity pneumonitis among office building employees. Hypersensitivity pneumonitis is a flu-like illness characterized by episodes of fever, chills, malaise, muscle aches, and, usually, chest tightness. These symptoms have usually improved after the affected workers leave the building (for vacations and weekends) only to recur when they return to the work environment. The cause of this illness is an immunological sensitization to microorganisms in the building environment. However, detection of specific microorganisms associated with an outbreak is often quite difficult. Growth of such microorganisms in a building is usually favored by a wet environment, and often the source of the causative microorganisms is an air conditioning or humidification system. Environmental evaluation of these outbreaks is quite complex because of the variety of microorganisms which may be associated with the disease, the intermittent nature of some of these outbreaks, and our lack of knowledge about the health effects of microbial contamination of building environments and the lack of appropriate guidelines for controlling these outbreaks. NIOSH has recently conducted considerable research toward the development of better methods for assessing contamination in these work environments. However, control of

the contamination problems in buildings where outbreaks of hypersensitivity pneumonitis have occurred has been quite difficult. In one building complex, for example, several million dollars has been spent in an attempt to alleviate a hypersensitivity pneumonitis problem. At this time it is unclear to what extent this effort has been successful. This underscores the need for better methods to assess and prevent these outbreaks.

5. Contamination from Chemicals Used in Building Maintenance: In a few evaluations, we have been able to relate contamination in a building to substances used in building maintenance. For example, carpet cleansing agents may cause eye irritation and other symptoms in exposed office workers. Agents added to the building's humidification system (amine chemicals) have caused dermatitis and eye irritation. Pesticide use may also cause symptoms in building occupants.

6. Inadequate Ventilation: In over half of our indoor air quality investigations, we have found that the major cause of the problem is inadequate ventilation of the building. The symptoms experienced by office workers in these buildings are usually non-specific, but they are notably similar from building to building and include headache; eye, nose, and throat irritation; fatigue; and in some cases, dizziness and nausea. The illness experienced by many of these workers is severe enough to result in lost work-time, reassignment, and even termination of work.

Although complaints usually originate in one section of a building, questionnaire surveys of the building occupants usually reveal that the symptoms are widespread, affecting both professional and non-professional workers.

Because of the highly emotional nature of many of these situations, the complexity of the buildings, and the fact that environmental monitoring may be inconclusive, the results of the investigations are often quite difficult to interpret.

Although more serious illnesses (cancer, heart attacks, etc.) are occasionally attributed to working in these building environments, no clear evidence of health problems more serious than apparent allergic reactions in a few individuals to specific office contaminants has been found. However, our studies have not addressed the question of whether there are long-term health effects associated with working in these environments. Nearly all of our studies have been short term and have been limited to a particular office environment.

In situations in which there is widespread reporting of non-specific symptoms, no specific sources of environmental contamination, and the generally low concentrations of contaminants found in our environmental monitoring, we have usually concluded that inadequate building ventilation is the cause of the employees' complaints. Often, for energy conservation reasons, the amount of fresh air being introduced into the office environment has been limited. In some cases, almost no provision for introducing fresh air has been made. Seasonal cooling or heating requirements often lead to intermittent reduction of fresh air through the building ventilation system. The design of the building, or modifications made to the building after construction, may also interfere with the distribution of fresh air into certain work areas.

Although only low levels of specific contaminants may be identified by the environmental monitoring, we believe that the cause of symptoms in these situations is the buildup of low levels of multiple "natural" building contaminants, including off-gasing from building materials, emissions from office machinery, and solvents and other chemicals used in office work and building maintenance. Inadequate ventilation in the building does not provide for the exhausting of these contaminants. Undoubtedly, cigarette smoke plays a role in increasing the contamination of the office air and in producing symptoms in smokers and exposed non smokers. Overcrowding in the office may also aggravate the problem.

Unfortunately, we have not identified a specific chemical contaminant, the concentration of which would allow us to say that more ventilation is needed for these buildings. For evaluating the adequacy of building ventilation, our investigators use the ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.) guidelines, "Ventilation for Acceptable Indoor Air Quality." These guidelines recommend a minimum of 5 cubic feet per minute (cfm) of outdoor air per person in an office area. The recommended minimum is increased to 20 cfm if smoking is permitted in the office. I will not go into details on these guidelines, because I understand that this was discussed at yesterday's hearings. However, I would like to point out that there has not been a systematic study to demonstrate that following these ventilation guidelines will prevent the development of the type of symptoms reported in our investigations.

Nevertheless, we usually cite these standards in our reports as a guideline for improving the ventilation in buildings where we have found this type of problem.

Thus far in my testimony, I have described CDC research and investigations related exclusively to indoor air pollution in the workplace. CDC has also initiated research that includes non-occupational exposures to indoor air pollution.

In 1982, CDC's Center for Environmental Health (CEH) conducted a survey of State health department programs for hazard evaluations of non-occupational indoor air pollution. The survey included questions regarding the type of State programs established to deal with this problem, the appropriate contacts within the State for responding to the problem, and a section on State evaluation of complaints related to presumed exposure to formaldehyde. Responses were obtained from each of the 50 States, the District of Columbia, the City of New York, Puerto Rico, and the U.S. Virgin Islands. The results of this survey are to be sent to the States very shortly.

Survey results you may find interesting are: Of the 50 States and the District of Columbia, (1) thirty-two (63%) have a specific program or person(s) responsible for nonoccupational indoor air pollution; (2) twenty-eight (55%) can evaluate formaldehyde exposures; and, (3) forty seven (92%) have no existing or proposed non-occupational indoor air pollution exposure standards. Other information obtained in the survey relates primarily to questions of sampling capabilities, sampling and analytical techniques, and use of data. The results underscore the wide range of State capabilities in this area, and the diverse programmatic responses to a commonly occurring exposure hazard such as formaldehyde. The identification of the responsible program component for indoor air pollution activities within each State health department gives us a valuable list of contacts with whom technical information and guidance on air pollution issues can be exchanged.

NIOSH and CEH are attempting to develop guidelines that can be used by others for investigation of building related air pollution problems. NIOSH is developing practical recommendations for controlling the hazards (e.g., reduce the microbial contamination and increase ventilation), and working to disseminate this information to other groups concerned about indoor air pollution.

In response to your request for suggestions for further research on indoor air quality. I would like to outline three major, interrelated needs:

1. Better methods of assessment: Better methods to assess indoor air quality are needed to identify indoor air hazards. NIOSH has done considerable

work in assessing chemical and microbial contamination in "problem" buildings, but we do not believe that adequate methods are yet available. For buildings where we attribute the problem to inadequate ventilation, contaminants responsible for causing symptoms in exposed workers need to be identified and appropriate methods developed for their assessment and control.

2. Epidemiological Studies: Careful epidemiological and medical studies need to be done in buildings to determine the prevalence and incidence of symptoms and other medical conditions in relation to the building environment. For both buildings with inadequate ventilation and buildings with outbreaks of hypersensitivity pneumonitis, careful followup environmental and epidemiological studies need to be done to determine to what extent corrective actions have actually improved the health of the building occupants and to determine what, if any, long term health effects there may be. Such studies could provide the basis for better guidelines to controlling these problems.

3. Control Methods: Research needs to be done to determine how changes in a building ventilation system may affect exposures to building contaminants, such as asbestos or microorganisms. Research is also needed to develop better methods for controlling exposures to other office contaminants at their sources.

Thank you for the opportunity to describe our indoor air quality activities. I will be happy to answer any questions.

Mr. FUQUA. Thank you very much.

We will now hear from Dr. Stolwijk.

Dr. STOLWIJK. Thank you, Mr. Chairman. I am very grateful for the opportunity of testifying before this joint hearing on what I feel is a subject of great importance to public health.

The previous speaker has dealt very ably and very competently with the problems as they exist in large buildings and on occupational exposures. As a Department of Public Health, we have a very serious concern with the individual residential exposures as well. They may be more difficult to monitor, more difficult to evaluate, but they do constitute an even larger amount of time that people spend in them and they do constitute an environment in which a number of changes have taken place in the last 10 or 15 years which we believe have led to a greater incidence of problems, even in the home environment.

The attention given to this problem before 1973 was sporadic and largely exploratory. As you are aware, the Environmental Protection Agency did some exploratory—or commissioned some exploratory studies prior to that time, and it was also becoming evident from investigators who were working on the adverse health effects of pollutants in the outdoor environment that the indoor environment was modifying these exposures to such an extent that the actual exposure was difficult to establish.

Up to then, the common approach in epidemiological studies of the adverse effects of air pollution on human health had been to estimate the exposure based on outdoor measurements of air pollutant concentration. If an epidemiological study is designed to measure the effect of such an air pollutant on health and the degree of exposure is inappropriately measured or assigned, then the effectiveness and credibility of such a study is severely compromised.

A little earlier than in this country, in Northwestern Europe, the increases in the price of energy for heating and air-conditioning occurred somewhat earlier and somewhat more sharply than they did in this country. Building traditions and methods of operations of buildings in Northwestern Europe also varied from the common experience in this country. As a result, they experienced problems with indoor air quality considerably earlier than we did. They build very much tighter buildings and they also, in the construction of new buildings, started to introduce large amounts of chipboard and large amounts of man-made fibers and man-made materials which led to off-gassing in a number of buildings in Norway and Denmark and in the Netherlands which caused severe problems and even delayed the occupancy of such buildings seriously.

When the costs of heating and air-conditioning are high, or when they increase substantially, there is that kind of incentive to reduce infiltration and/or the ventilation of a building. In a large building, as much as half of the total heating and cooling costs are derived from the need to heat or cool the outdoor air used for ventilation, and clearly that then becomes a very convenient and simple way of reducing the total energy cost by reducing the rate of air intake. The result is that all pollutants which are produced or released indoors get diluted less and get diluted more slowly, and their concentrations in the indoor air will increase.

At the same time we find an increasing variety and quantity of synthetic materials being introduced into the indoor environment, into the domestic environment as well as into the office environment, especially in the form of furnishings, finishes, and cleaning and maintenance materials. Effectively, the exposures to formaldehyde, for instance, have undoubtedly increased over the last 10 years. Unvented combustion products such as cigarette smoke and emissions from unvented combustion appliances have become a more serious threat to health as these infiltration rates have gone down and ventilation rates have been reduced. Similarly, every building will experience radon concentrations higher than outdoors under any circumstances due to the emissions from the underlying soil and from some of the building materials. But radon exposures will also increase in direct proportion to lowering of ventilation rates.

There is a broad consensus amongst people who have thought and written and investigated these areas that in the indoor environment the products which are of most concern are tobacco smoke, nitrogen dioxide, carbon monoxide, radon and its decay products, formaldehyde, sulfur dioxide, carbon dioxide, a large variety of volatile organic compounds, and finally, asbestos and manmade mineral fibers are being introduced into that environment.

There is no clear consensus on the relative importance of these pollutants in terms of the population exposure, or on their relative imact on public health. Responsible assessments of the overall public health impact cannot be made at this time because we lack adequate data about distribution and severity of exposures in the population, and we lack adequate data about the exposure-response relationships. We know from studies on cigarette smokers that tobacco smoke increases the incidence of bronchitis and other respiratory diseases, and that it is a major cause of lung cancer. But we do not know at this time the relative exposure of nonsmokers to side-stream tobacco smoke, nor do we know with enough certainty what impact such exposures have in the nonsmoking population.

There is evidence that exposures to NO_2 will reduce the effectiveness with which we fight off respiratory system infections. If such exposures to NO_2 produce a 50-percent increase in respiratory infections from influenza to pneumonia, an individual might not notice such an increase in the immediate surroundings. But on a national scale, this would increase the total burden of disease and disability in what most people would consider a totally unacceptable manner.

This kind of effect can only be studied in properly designed epidemiological studies and they, I believe, should be mounted in connection with this indoor air quality problem which has over the last 10 or 15 years undoubtedly increased in severity.

There is very often no convenient way for the public to assess the radon concentration or the carbon monoxide concentration in indoor spaces because they cannot be noticed in any convenient manner by the public. The risk from these has again clearly increased, but the magnitude of the risk cannot be responsibly estimated at this time without much more extensive data.

We can deal with and we can find out more easily about acute exposures because we find that, unfortunately, there are always incidences of serious aggravational disease or death which follow excessively high exposures of very sensitive or vulnerable individuals, and for almost any pollutant that has been identified in the indoor environment, we can find reports of cases where very serious consequences have taken place because of such exposures. Clearly, it is also clear that a much larger number of such incidents do not get recognized or are not reported in the literature.

What we have, from a public health point of view, is a widespread risk, an opportunity for damage to be occurring. We know the total amount of damage has clearly increased during the last decade, and we also know that the public, especially in the household, can usually not recognize this risk, and it is also clear that energy saving behavior will increase the risk. Ultimately, the public is going to have to make a tradeoff between accepting these risks or accepting the cost of reducing the risk. That cost will, in general, also have to be borne by the household or by the building in which these risks actually occur.

The cost of such a reduction could manifest itself in increased ventilation and the associated cost in energy or heat transfer devices necessary to save the energy, or it could manifest itself as a restriction of emissions such as limiting cigarette smoking or abandoning the use of unvented combustion heaters. Responsible decisionmaking will require more information than is currently available.

The subject of this hearing is the current status and future needs in indoor air quality research. The current status of our knowledge has been assessed I think by a number of panels of experts. I have personally been a member of two World Health Organization panels which were convened for the purpose of assessing what kind of liabilities were actually present in the indoor air quality deterioration that has been occurring over the last 10 years. The National Academy has convened a committee on the subject. I think that the current state of our knowledge has been very thoroughly evaluated and has been found to be adequate to develop the fact that there is a problem and that it has also made very clear that the current status of our knowledge is not adequate to assess what sorts of total public health impact actually is occurring in the country.

There is an increased level of effort required to gain that information, and that level of effort has, I think, in part not come about because we lacked really promising avenues or methodologies of studying these problems. I think the various conferences and the serious efforts made by the professionals in this field have resulted in the last few years in a much clearer picture of the approach that must be taken.

One important need for the immediate future is the characterization of our total building stock in terms of effective ventilation rate. At the moment we cannot account effectively for the really sizable reduction in total energy consumption in this country in the residential environment. We do know that there have been reductions in the order of 15 percent of the total energy consumption for a particular residence in several areas of the country. This is a reduction which exceeds the fondest expectations of energy conservation officials in 1975. We at the moment cannot tell you how these reductions have actually been achieved. We do know that a great many buildings have been tightened up and that has resulted in a reduction; we know that people set their thermostats lower and that has resulted in a reduction; and we believe that in a large number of spaces people have resorted to space heaters to create small islands of comfort in the wintertime and to keep the rest of the residence at much lower temperatures. All of these efforts will have consequences on the—our behavioral efforts, to a large extent, they will have consequences for the health of the occupants and at the moment we lack the information to tell us what sorts of methods people have actually used to reduce their energy consumption. We do have a suspicion that many of these methods, in fact, may be counterproductive for the health of the occupants.

We have recently conducted a study for the Consumer Product Safety Commission, which you may have been told about yesterday, which dealt with the effects of kerosene heaters, unvented kerosene heaters, as they are now in widespread use, a number of millions. In this study, one of the things that I have become very impressed with is the absolute need to combine the skills of a number of different disciplines simultaneously on such a problem. One can have the best methodology for physical measurements, but in fact it is necessary in these studies to obtain a sample, a proper probability sample of the spaces that one ought to study. One needs to gain access and cooperation from these spaces and from these particular spaces when a proper sample has been drawn, and one needs to also evaluate the behavioral contributions of the people living in these spaces or using these spaces.

It is quite clear from our study and from other studies which have been carried out by a number of investigators that the behavior of the occupants has a very serious effect on the level of air quality that one finds in a space. Just the analysis of the spaces by themselves is not going to be as effective as it should be, because we will not know what the behavior of the occupants was and how it might have affected the overall air quality in such a building.

I believe that we now have agreement on the kinds of methodologies which need to be used, and I think these methodologies will be effective. The time for an effective and coordinated effort to study this problem on a much larger scale than before is now if we are to offer the public the information on which sound personal decisions can be based, that will improve their health. I think there is an increasing commitment and recognition of the importance of participation of the public in measures which serve to promote health and to prevent disease, especially in the behavioral area, and this I think is an important area in which we currently lack the effective information to be transmitted to the public.

I think it is also of the greatest importance that the efforts, when they get mounted, be coordinated on as many fronts simultaneously as possible, and that these studies be planned in advance and that the protocols be agreed to by experts who have the necessary experience. I believe it is also very important that such efforts be conducted with the participation of both the behavioral scientists as well as the physical scientists, as well as the health scientists, that have to make contributions to this if these studies are to be as effective as they should be and as the Congress and the public has a right to expect.

Thank you very much.

[The prepared statement of Dr. Stolwijk follows:]

Testimony before a joint hearing of the Subcommittees on Energy Development and Application and the Natural Resources and on Agriculture Research and Environment.

Indoor Air Quality Research: Current Status and Future Needs.

August 3, 1983 by Jan A.J. Stolwijk, Professor of Epidemiology and Public Health and Chairman of the Department of Epidemiology and Public Health, Yale University School of Medicine; Associate Director John B. Pierce Laboratory, New Haven CT 06510.

Mr. Chairman, I am grateful for the opportunity to testify before this joint hearing on what I feel is a subject of great importance to public health. My testimony is based on personal experience in Indoor Air Quality Research, on membership in an NAS/NRC Committee on Indoor Pollutants, on my participation in two working groups of the World Health Organization for the European Region, and on insights developed in an environmental epidemiology program in our Department at Yale University.

Concern about indoor air quality may appear relatively recent, but in fact air quality in the indoor workplace has been the subject of concern and extensive research for many years. Before 1973 the attention given to non-occupational indoor air quality was sporadic and largely exploratory. A number of investigators pointed out and demonstrated that non-occupational indoor environments could have indoor air quality characteristics which are substantially different from the outdoor atmosphere.

Up to then the common approach in epidemiological studies of the adverse effects of air pollution on health had been to estimate the exposure based on outdoor measurements of air pollutant concentration. If an epidemiological study is designed to measure the effect of an air pollutant on health and the degree of exposure is inappropriately measured or assigned, then the effectiveness and credibility of such a study is severely compromised.

The attention demanded by and given the indoor air quality problem increased substantially, both in Northwestern Europe and the U.S. and Canada, with the sharp increases in the price of energy for heating and air conditioning between 1970 and 1980. When the costs of heating and air conditioning are high or when they increase substantially there will be an incentive to reduce infiltration and/or ventilation of a building. In a large building as much as half of the total heating and cooling costs derive from the need to heat or cool the outdoor air used for ventilation. The incentives to reduce infiltration by tightening of the building envelope and to reduce the rate of intake of outdoor air into the ventilation system produce lower rates of air exchange with the outdoor environment. The result is that all pollutants produced or released indoors get diluted less and more slowly, and their concentrations in the indoor air will increase.

At the same time there is an increasing variety and quantity of synthetic materials being introduced into the indoor environment, especially in the form of furnishings, finishes, and cleaning and maintenance materials. Exposures to formaldehyde have undoubtedly increased over the years. Unvented combustion products such as cigarette smoke, and emissions from unvented combustion appliances have become a more serious threat to health as the infiltration rates and ventilation rates have been reduced. Every building will experience radon concentrations higher than outdoors due to emissions from the underlying soil and from some building materials. Radon exposures also will increase in direct proportion to lowering of ventilation rates.

There is a broad consensus that the pollutants in the indoor environment which are of the most concern are: tobacco smoke, nitrogen dioxide, carbon monoxide, radon and its decay products, formaldehyde, sulfur dioxide, carbon dioxide, volatile organic compounds and asbestos and manmade mineral fibers. There is no clear consensus about the relative importance of these pollutants in terms of the population exposure, or their relative impact on public health. Responsible assessments of the overall public health impact can not be made at this time because we lack adequate data about the distribution and severity of exposures in the population, and we lack adequate data about the exposure-response relationships. As an example we know from studies on cigarette smokers that tobacco smoke increases the incidence of bronchitis and other respiratory diseases, and that it is a major cause in lung cancer. We do not know the relative exposure of non-smokers to side-stream tobacco smoke, nor do we know with enough certainty what impact such exposures have in the non-smoking population.

Similarly, there is evidence that exposures to NO2 will reduce the effectiveness with which we fight off respiratory system infections. If such exposures produce a 50% increase in respiratory infections from influenza to pneumonia, an individual might not notice such an increase in her immediate surroundings, but on a national scale this would increase the burden of disease and disability in what most people would consider an unacceptable manner.

All pollutants released indoors increase their concentration when infiltration and ventilation are reduced. Radon, which is released by the underlying soil and by some building materials will increase in concentration when effective ventilation is reduced. Its main effect will be in the lungs where it will increase the risk of lung cancer. There is no convenient way for the public to assess the radon concentration in indoor spaces, and our current knowledge about actual concentrations and their distribution is inadequate. The risk to the population has clearly increased since 1970, but the magnitude of this risk cannot be responsibly estimated without much more extensive and improved data.

For acute exposures there are a large number of case reports which show that indoor air pollutants have caused serious aggravation of disease, or death, usually by excessively high exposures of sensitive or vulnerable individuals. A much larger number of such incidents do not get recognized, or are not reported in the literature. From a public health point of view we have a widespread risk, a risk which has clearly increased during the last decade, and a risk which can have serious consequences. It is also clear that the public can usually not recognize this risk, and it is clear that energy saving behavior will increase this risk. Ultimately the public is going to have to make a trade-off between this risk, and the cost of reducing this risk. The cost of this reduction could manifest itself in increased ventilation and the associated cost in energy or in heat transfer devices, or it could manifest itself as a restriction of emissions such as limiting cigarette smoking or abandoning the use of unvented combustion heaters. Responsible decision making will require more information than is currently available.

The subject of this hearing is the current status and future needs in indoor air quality research. The current status of our knowledge is clearly inadequate for an assessment of indoor air quality, although it is adequate to identify the problem as one requiring an increasing level of effort.

The research needed in this area to make better assessments possible is difficult because of the extremely large numbers of spaces involved and because of the diversity in characteristics. Indoor air quality is not only affected by ventilation rate and by internal and external sources of pollutants, but occupant behavior is a very important and quite variable factor.

One important need for the immediate future is the characterization of the building stock in terms of effective ventilation rate, and in terms of the internal sources and occupant behavior. Such studies should be designed and coordinated so that a representative sample of indoor non-occupational spaces could be assessed. The design and conduct of such surveys will require the combined methodologies of the physical, social and epidemiological disciplines. It is possible to design schedules of measurement and monitoring in which costly intensive monitoring is carried out in relatively few buildings and in which progressively less intensive measurements are made in other groups of buildings with increasingly large numbers of buildings. Such measurements should be combined with suitably designed interview surveys of the occupants in order to gain simultaneous insights into occupant behavior and the potential sources introduced as consumer products.

We have recently carried out a small scale study of about 180 households which used unvented kerosene heaters, with 180 adjacent residences without such heaters as controls. We evaluated the exposure to a number of pollutants but were principally interested in nitrogen dioxide, and we are still evaluating the reports of the health status of the occupants of these 360 residences over a three month period. This study has convinced us that only comprehensive studies of total air quality and of the health status of the occupants are going to be cost effective. Ventilation rates and occupant behavior affect all air pollutant concentrations simultaneously so that a study adequate for estimating exposure to one pollutant can estimate the exposure for all pollutants at very little additional cost. Assessment of the health status of occupants in a prospective study can be added to any study of the time course of exposures, at very little additional cost.

Most of the studies so far, including the one just described are cross-sectional in time, last for only a short time and are thus not able to study illnesses which develop only after very long exposures. Acute respiratory infections can be studied this way but the effect of increased radon concentration on lung cancer risk can only be seen many years later and has to be studied using different methods.

Studies of the adverse health effects of indoor air pollutants will require methodologies which are different from those used in the past. The methods are however available and the time for an effective and coordinated effort is now, if we are to offer the public the information on which sound personal decisions can be based.

Mr. **Fuqua**. Thank you very much. We appreciate both of your statements.

Dr. Stolwijk——

Mr. **Sensenbrenner**. Mr. Chairman, I have an opening statement I would like to ask unanimous consent to be entered into the record.

Mr. **Fuqua**. Without objection, unaltered.

Mr. **Sensenbrenner**. Word for word, Mr. Chairman.

[The prepared statement of Mr. Sensenbrenner follows:]

OPENING STATMENT OF THE
HON. F. JAMES SENSENBRENNER, JR. (R-WIS.)

BEFORE THE JOINT EDA/NRARE SUBCOMMITTEE HEARING ON
INDOOR AIR QUALITY RESEARCH:
CURRENT STATUS AND FUTURE NEEDS

AUGUST 3, 1983

THANK YOU, MR. CHAIRMAN, FOR THIS OPPORTUNITY TO EXTEND A WELCOME TO OUR DISTINGUISHED WITNESSES.

WE LOOK FORWARD TO THEIR TESTIMONY ON EFFORTS THAT HAVE BEEN UNDERTAKEN TO UNDERSTAND THE HEALTH EFFECTS OF INDOOR AIR POLLUTION, BY THEIR RESPECTIVE ORGANIZATIONS, AND THE FEDERAL GOVERNMENT.

AS THIS COUNTRY HAS UNDERTAKEN EFFORTS TO CONSERVE OUR ENERGY CONSUMPTION, THROUGH THE REDUCTION IN ENERGY LOSS THROUGH BUILDING VENTILATION SYSTEMS, WE MUST UNDERSTAND THE CORRESPONDING EFFECT THAT THIS ACTION WILL HAVE UPON A BUILDING'S ENVIRONMENTAL QUALITY. FURTHER, AS WE STRIVE FOR INCREASES IN OUR TECHNOLOGY, THE HEALTH EFFECTS OF THESE NEW TECHNOLOGIES UPON THEIR USERS MUST BE EXAMINED. CONSERVATION EFFORTS AND TECHNOLOGICAL ADVANCES MUST NOT BE UNDERTAKEN AT THE EXPENSE OF HUMAN HEALTH. AS WE WERE INFORMED BY YESTERDAY'S PANEL, MUCH OF THE TECHNOLOGY REQUIRED FOR IMPROVING OUR INDOOR AIR QUALITY IS ALREADY IN EXISTENCE. WHAT IS NEEDED IS SITE-SPECIFIC RESEARCH ON THE PROPER IMPLEMENTATION OF THE TECHNOLOGY IN A GIVEN SITUATION. THE ISSUE THAT MUST BE ADDRESSED CONCERNS THE PROPER ROLE OF THE FEDRAL GOVERNMENT. YOUR INSIGHT ON THIS ISSUE AND ON WHAT RESEARCH REMAINS TO BE UNDERTAKEN IS APPRECIATED.

Mr. **Scheuer.** I also have a statement that I would like unanimous consent to put in the record.

Mr. **Fuqua.** Yes; without objection.

[The prepared statement of Mr. Scheuer follows:]

OPENING STATEMENT, AUGUST 3, 1983, OF HON. JAMES H. SCHEUER

A large percentage of the American population is affected by the many forms of indoor air pollution including smoking.

A 1981 National Academy of Sciences publication on Indoor Pollutants included a section on smoking.

One survey found that approximately 70 percent of homes have at least one smoker in residence.

The study estimated that "exposure of the nonsmoker in a smoke-filled environment (is) one-hundredth to one-tenth of the smoker's exposure."

Another study was conducted on the long-term effects of exposure to cigarette smoke on the nonsmoker especially in the workplace.

The National Academy of Sciences report concluded, that "* * * data do suggest that exposure to cigarette smoke may have a deleterious effect on the health and function of the healthy nonsmoker in the work environment."

What impact this will have on the nonsmoker's health is not clear.

Additional research is needed in this and in other areas in order to resolve these issues.

Today's hearing will address this and other research studies in indoor air pollution.

Additionally, we will hear testimony from the Department of Energy and the Environmental Protection Agency witnesses, who will explain the Federal programs in indoor air quality.

The 1984 EPA appropriations for EPA contains $2 million for indoor air quality studies.

Therefore, this hearing is important so that we may examine the Federal program and give guidance to the agencies.

I want to thank the witnesses for being here today and am looking forward to hearing the testimony.

Mr. **Fuqua.** Dr. Stolwijk, based on your studies, how would you compare a typical American's exposure to indoor air pollutants versus outdoor air pollutants, and which is probably the greater health risk?

Dr. **Stolwijk.** Well, unfortunately one can't make a general statement in that respect. For instance, in the case of ozone, the outdoor exposures clearly I think are more severe than the indoor exposures. It is very rare to find a concentration of ozone indoors that is even half that of what the concentration is outdoors.

For most of those pollutants for which there are indoor sources, it is also quite clear that in almost all circumstances the concentrations indoors are higher than they are outdoors. And that would include the combustion products. Whenever there is unvented combustion taking place inside an indoor space, you will find that all those pollutants associated with combustion will occur indoors at concentrations higher than they will outdoors.

Mr. **Fuqua.** You stated in your testimony to the effect that our current knowledge is inadequate to assess indoor air quality. What—could you elaborate on that statement, even though you also say since 1970 that we know more about air quality and it's becoming a more serious risk?

Dr. **Stolwijk.** The difficulty with assessing the quality of the air indoors stems from the fact that the number of spaces, each of which is characterized by their own sources and their own sinks, and by their own exchange rates with the outdoor environment, each of these spaces is a universe of its own. And to try and measure all of these spaces, or evaluate all of these spaces, it clearly is going to be unnecessary and not doable.

What we need to do is to find spaces that are sufficiently—a limited number of spaces that are sufficiently characteristic of the whole building stock and of all spaces so that we can in some smaller sample of the total universe make these determinations. In the past, most of these determinations have actually been made on buildings which were often not occupied and which often were very intensively monitored in a very small number of spaces. What I believe is going to be necessary is that we measure in a very small number of spaces, very intensively and very accurately, both in time and space, what the concentrations are of a number of pollutants.

I think we then need to identify a larger number of spaces——

Mr. **Fuqua**. Now, whose responsibility is it to do this?

Dr. **Stolwijk**. This responsibility would be held, I believe, by some—would be best held by some scientific advisory board that would be installed to approve the protocols that people actually would adopt. I think that it probably is not convenient at this time for any existing agency to deal with the complexity that is actually now—that is going to need to be addressed. I think an agency can administer this, but for an agency to actually develop the necessary protocols by itself I think is going to be very difficult.

Mr. **Fuqua**. Are you proposing that this be financed privately or should—is there a Federal responsibility?

Dr. **Stolwijk**. I think that, what I would hope would happen is that both the Federal Government and a number of industries would take an active interest. I believe that, in fact, a number of associations are taking an active interest in, mostly from a protective point of view. I think the Federal Government should have quite an important role because the kind of protection of the public that is I think needed, and the kind of advice to be given to the public that is needed, can really only effectively come from the Federal Government. The State governments lack the expertise and the experience to carry out these kind of studies. They lack the resources. And I think this is a responsibility for the Federal Government which then provides insights and advice which goes directly to the benefit of the public in their own personal decisionmaking.

Mr. **Fuqua**. Thank you.

Dr. Melius, we have a lot of people here in this building that use office machines, copy machines, et cetera—not here, but all over the Federal Government. What type of common problem do they face?

Dr. **Melius**. I think first of all many of the problems associated with copying machines have been recognized by the manufacturers. There usually are provisions in terms of where they're set up to control hazards, or instructions to properly ventilate these machines.

However, I think there is need for an awareness that there are a variety of things that can be, contaminants that can be produced from these. Ozone is very common with copying machines, various copying machines. The spirit duplicators which are more often used in schools, ditto machines, have serious problems with methyl alcohol or methanol exposures.

There has been concern recently—for example, IBM with a compound called trinitro fluorenone which was suspected of being a cancer-causing agent, and there is a lot of concern over what the exposure could be to that from routine use of copying machines of specific types. Similar problems, questions have arisen from some of the other manufacturers. So there are serious—methacolates can also come from some of the signature machines and telecopying machines. In fact, I think we did a survey in this building, one of the congressional offices, a few years ago concerning exposures to methacrylates from one of the signature machines.

Mr. FUQUA. Mr. Scheuer.

Mr. SCHEUER. What is the so-called—Dr. Melius, what is the so-called "sick building" syndrome?

Dr. MELIUS. That's a question I had, too. The first I heard the exact term was, I think, when I read some of the EPA testimony. But I think we refer to it as a common problem that we become very often involved in, where there is a high prevalence of complaints from workers within an office building or similar facility, where that is not readily explained by exposures from building materials or from outside the building. Many of these would be—we call the term a "stuffy building" syndrome, where there is inadequate ventilation in the building. Or it can be with the hypersensitivity pneumonitis question, where you have a serious problem with reactions to microorganisms present in the building environment.

We get involved in many of these investigations. They are difficult, a lot of concern on the part of employees there, what are the long-term effects for them. Often a lot of media coverage and a lot of concern over what can be done to prevent future problems. They are not easy to correct, some of these problems. It costs—millions of dollars have been put into some buildings in an attempt to correct problems, and they don't—if you can't measure something directly, it is difficult to show that the problem has gone away. Symptoms may persist and people's concerns may persist for quite some time with that.

Mr. SCHEUER. If you could just sum up briefly, how common a problem is this, how serious is it, what can we do about it, and what kind of research do you think ought to be done further on this problem?

Dr. MELIUS. It is difficult from—I don't think anybody has any data on how common a problem it is. We respond—NIOSH responds to requests about these buildings, but it is not—we are not the only group responding to these requests. Not everything gets reported to us.

My own perception is that the problems have increased dramatically over the past several years. Some of this is increased awareness on the part of the public of possible hazards in buildings. Some of it is due to energy conservation and some of the other reasons that I outlined in my testimony and as has been pointed out by others.

I think our usual response is to first go out and look at the building, examine are there sources of contamination within the building—formaldehyde foam insulation, exhausts from a garage next door, something like that—measure for contaminants within the building, and determine what sort of symptoms people are experiencing and looking at the building ventilation system and can we pinpoint the particular cause of this problem. And then to develop, based on our evaluation, some practical recommendations to improve that problem.

In some cases these recommendations are very easy—adjusting the ventilation system, or moving a copying machine and so forth. Other times they can be very expensive and require major renovations in a building. That becomes something on the part of building management to do.

Mr. **Scheuer**. Thank you very much.

I think we will recess now for about 10 or 12 minutes and comeback after this rollcall vote.

[Whereupon, the subcommittees were in recess.]

Mr. **Fuqua**. The meeting will resume.

I think prior to the recess Mr. Scheuer was asking some questions and had not concluded as yet.

Mr. **Scheuer**. Thank you, Mr. Chairman.

Mr. Chairman, I want to express my appreciation to the witnesses for their excellent testimony. I would like to ask them both for them to answer at will some questions about smoking, both smoking in the home and smoking in the workplace.

As I understand it, Mr. Chairman, the effects of involuntary smoking on the would-be nonsmoker who turns out to be a willy-nilly smoker, includes general annoyance and irritability, irritation, increase in blood pressure and heart rate, allergic reactions and various others.

Dr. Melius, can you tell us what your agency, what NIOSH is undertaking to examine these health effects and to assess the risk of smoking on the involuntary smoker in the workplace?

Dr. **Melius**. NIOSH does not have a specific program to deal with the effects of cigarette smoking, per se. We do work on it in relationship to certain types of other occupational exposures such as asbestos, other lung carcinogens. We do deal with it in terms of the indoor air quality investigations that we work on.

I do know that my department, Health and Human Services, does have a fairly extensive research program looking into the effects of smoking, both on smokers and exposed nonsmokers. Certainly there are a variety of health effects—the previous speaker spoke about in his outline there—including concern about cancer risks for exposed nonsmokers, aggravation of lung disease and of heart disease in exposed nonsmokers, and concerns about symptoms such as eye irritation and so forth. Certainly within so-called stuffy buildings or tight buildings ventilation guidelines need to take into account the fact that there are a certain percentage of smokers there. The present ASHRAE guidelines include quite a large margin increase in ventilation if you do allow smoking within an office space.

Mr. **Scheuer**. I have read that smoking has a deleterious effect, a harmful effect, on productivity in the workplace. Can you give us any——

Dr. MELIUS. I don't know if there—I am not aware of any studies, per se, on that, but certainly I think it is commonsense that if you're in an office area or something and there is a lot of—and you're experiencing eye irritation, your allergies are aggravated, whatever, that is not going to be conducive to work productivity, any more than any general problems that you're having in your office area are going to be. I mean, productivity will be decreased when people are having problems missing work and so forth.

Mr. SCHEUER. But you don't know?

Dr. MELIUS. I don't know if there are any studies, per se, that demonstrate that——

Mr. SCHEUER. Now, your agency has, of course, responsibility for safety in the workplace——

Dr. MELIUS. Correct.

Mr. SCHEUER [continuing]. And presumably productivity in the workplace.

Dr. MELIUS. Not—I don't think it's directly as——

Mr. SCHEUER. Well, changes in productivity resulting from psychological and other health hazards, right?

Dr. MELIUS. Certainly.

Mr. SCHEUER. OK. Don't you think it would be appropriate for your agency to be conducting some research, at least to be part of a coordinated research effort?

Dr. MELIUS. I think our agency, overall agency, HHS and NIOSH, certainly would be willing to coordinate our research efforts in this area. NIOSH does have research on effects of, for example, stressful situations in the office on productivity and other measures of psychological stress for workers. Certainly it is one area that does need to be looked in. I am just not personally familiar with all the literature on that, if there is any good information on that particular issue.

Mr. FUQUA. Would the gentleman yield?

Mr. SCHEUER. Of course.

Mr. FUQUA. Would you include in that the effects of alcohol and drugs on people's productivity and the effects it could have?

Dr. MELIUS. Though certainly it is a concern and something that NIOSH has also done research on, in terms of stress and other situations, we have a fairly active program on behavioral effects within the workplace, stress and so forth. These take into account such things as alcohol and drug abuse.

Mr. FUQUA. I would think somebody who had a three-martini lunch would probably be less effective in the afternoon than someone who had not, whether they smoked or not.

Dr. MELIUS. Certainly.

Mr. FUQUA. Or the involvement of drugs—and I'm not talking about illegal drugs. I'm talking about legal drugs.

Dr. MELIUS. In fact, NIOSH has done also work on the interactions between alcohol or certain drugs and the fairly serious toxic effects that can result from exposure to certain chemicals. It is something we have to take into account in doing that.

NIOSH is also initiating a program on health promotion within the workplace, tying in factors such as high blood pressure, cigarette smoking, alcohol, and exposures to occupational contaminants which may affect the health. It is an area that our new Director has stressed and we are pursuing an active program in that area.

Mr. **Scheuer**. Dr. Stolwijk, as an epidemiologist, can you tell us something about the effect—any conclusions you may have or any observations you may have as to the effects of tobacco smoke, both on the health and the psychological well-being of the nonsmoker, either in the home or the workplace or any other place?

Dr. **Stolwijk**. The Lung Division of the National Institutes of Health very recently held a workshop to arrive at an agreed-upon protocol for the study of the effects of passive smoking, the effects of smoke on nonsmokers.

The evidence that is currently in the literature is not altogether conclusive, I think. There is a clear indication that on sensitive individuals the effects of tobacco smoke on particularly sensitive individuals can be quite dramatic and disabling.

In terms of the effect that it has on children, I think there are some conflicting results, as you often get in epidemiology, especially when the studies that were undertaken did not have adequate power to determine the question that was originally posed with any kind of conclusiveness. Nevertheless, such studies do appear in the literature and they may appear to give evidence one way or the other. I think most of the people in the field consider that at the moment a somewhat unresolved issue as to what kinds of adverse health effects actually take—are the consequence of passive smoking.

There is clear agreement that the effect certainly is not beneficial. Just how adverse it is, and in what aspects, at the moment cannot be determined. I think the Lung Division of NIH is clearly planning to conduct a number of epidemiological investigations that will try to ascertain that with much more certainty than has been done in the past.

With respect to your question about productivity, as you know, the productivity or the effects of any kind of intervention on productivity are very difficult to measure at best. It is quite clear that the productivity of somebody who is extremely bothered by tobacco smoke is not going to improve. You might at the same time find that if you deny the use of tobacco in the workplace, then you might be able to find an equal number of individuals whose productivity is going to be reduced by that. So it's——

Mr. **Scheuer**. It's a Catch-22 situation?

Dr. **Stolwijk**. Sometimes it helps to segregate them, and that is a method that is being used with increasing frequency and I think it is effectively a very good one.

When you segregate smokers from nonsmokers, you also gain the advantage that you can provide smokers then with increased ventilation rates. The places where smoking is permitted can be given an increased ventilation rate with respect to all the other places. So the quality of the air can be improved in a number of different ways. The prohibition of smoking is a very effective one, but one that is not going to gain much popularity, but I think there are alternative ways such as the segregation in time and space of smoking activities so that at least people who are sensitive are not going to be unduly bothered.

Mr. **Scheuer**. Segregation in time and space. In other words, setting aside certain times where these people can smoke in a separated environment.

Thank you very, very, much, both of you.

Mr. **Fuqua**. Mr. Lewis.

Mr. **Lewis**. Thank you, Mr. Chairman. I have a couple of questions I would like to address to both gentlemen.

As you know, both the U.S. Department of Energy and the Environmental Protection Agency, as well as several other Federal agencies, have ongoing indoor quality control programs. Do you think these programs work well together, or is there a need for better coördination with these programs, for example, through one lead Federal agency, and what would you recommend as an overall strategy?

Dr. **Melius**. I think it's difficult for me to personally say how well they have worked together in the past. I think that one does not necessarily have to have a lead Federal agency to be involved, but coordination by one or two agencies would help.

I think if there's a commitment from all the agencies involved to work on problems, that one will get reasonable results from doing it that way. Our agency has worked in the past with EPA and other agencies on these problems and will continue to do so in the future. I think there's a commitment to share information and to work jointly on problems as they develop. We certainly have an active program with EPA in other areas and certainly can develop one in this particular area.

Dr. **Stolwijk**. Your question, I think, is a very important one. I think it is important to recognize that most of the Federal agencies that have an activity in the area of indoor air pollution are charged with a specific item. Their research efforts and regulatory efforts are, in general, limited to the kind of areas that they have expertise in and that they have experience in and that they have jurisdiction over. I think all of them discharge their responsibilities at the present time. Given the resources that they have available, I think they discharge them very well.

What I believe is needed is an increased effort which transcends the actual missions of each of these various agencies, and I believe that we need an assessment of what the national problem actually is in magnitude and in kind, and that can only be done—that cannot be done within the specific missions of each of these agencies. I think the Congress needs to take the lead and mandate a program which is in addition to these specific, more mission-oriented programs that are currently being conducted.

We will not get a national survey of the needs of the public in this area, we will not adequately be able to protect the public against the combined effects that sort of fall between the cracks of the responsibilities of the different agencies, until there is a coordinated program. I believe such a coordinated program should be under the direction of a suitably constituted advisory board which would have representation in it, all the various agencies that have a mission in this field, as well as from the various experts that currently, both in industry and in academia, have a role in conducting this type of research and in developing the control strategies that I think we need to be able to recommend to the public.

Mr. Lewis. Thank you.

The Science Committee has spent a great deal of time examining the role of the Federal Government in all areas of energy research and development. What do you believe is the most appropriate role of the Federal Government in indoor air quality R&D, and can organizations like EPRI and GRI carry the ball in this area by themselves?

Dr. Stolwijk. I think that if you let the EPRI and GRI carry the responsibility for the research effort by themselves, you will find that their activities will be limited in ways that are similar to the current limitations on the existing Federal agencies. They will be quite parochially directed at the particular problem of concern to them, and as a result, you will not get the comprehensiveness of an overall evaluation that will actually occur.

I can very easily see—and I would be very happy to see—collaboration and cooperation with these efforts as they are being mounted by industry at the moment. I think that's a very useful way to proceed both for the Federal Government and for the industry. I think the industry gains a level of credibility that it would be hard for it to get if it went it alone, and I think the Federal Government would find that there would be some relief from the overall expense that would be involved in such a study.

However, I believe that the overall direction of such an integrated effort logically belongs with one or more agencies of the Federal Government.

Mr. Lewis. Thank you.

Doctor.

Dr. Melius. I don't know if it's fair for me as a Government employee to say whether—to what extent the private sector should be involved and so forth. I think personally I would generally agree with the preceding statements.

I would also point out that as an agency in charge of a group that responds to problems in the workplace, indoor air pollution problems, that public health agencies will, both at the State, Federal and local level, will need to respond to these problems and will need to have access to information, methods of evaluation, and methods of control, and that those will largely need to be developed and disseminated within the Government and among the governmental agencies involved. It is a public health problem and one that different agencies, different public health agencies, within the Government are appropriately involved in responding to these problems.

Mr. Lewis. There have been peer reviews of private sector indoor air quality R&D activities. Are you aware of what level of effort there has been in the private sector—for example, in the utilities and universities or State agencies in this area—and what have these peer reviews indicated? Do you believe that they represent a serious commitment to solving the problem?

Dr. Stolwijk. I think there are peer reviews going on with these—within these organizations, or for these organizations, that reflects a growing insight on their part that, unless these efforts are peer reviewed and agreed to by otherwise uninterested parties, the credibility of these efforts will be so low that they might as well not carry them out.

I think to have effective peer review on a research program is not easy and it is for a trade association I think inherently a very difficult thing to do all by itself. If it is the only provider of funds, the submission of their activities to peer review is something that they attempt to do and I think in part succeed in, but it is a very difficult thing for them to effectively do because there tends to be a degree of participation in the overall decisionmaking at board levels that sometimes interferes with the effectiveness of the use of the peer review system.

Mr. LEWIS. Doctor.

Dr. MELIUS. I am not really familiar enough to respond to that question.

Mr. LEWIS. You can't—you're not familiar enough to say how peer review interacts with Government agencies and the universities?

Dr. MELIUS. We have not—my particular agency has not been involved in that activity in relationship to indoor air pollution. We have worked in other areas in conjunction with industry groups on particular problems and working out jointly in terms of peer review, and from joint studies with these groups have found that it can work well with them. I can't really say we have had any experience in this specific area.

Mr. LEWIS. I see.

Thank you, Doctors. Thank you, Mr. Chairman.

Mr. FUQUA. Thank you very much. We deeply appreciate both you gentlemen being here this morning and the contributions that you have made. Thank you very much.

Our next witness will be Mr. Joseph Tribble, the Assistant Secretary of Energy for Conservation and Renewable Energy, and I understand he will be accompanied by Dr. James Kane, the Deputy Director.

Dr. KANE. Mr. Tribble must have just stepped out. He was in the back of the audience just a moment ago.

Mr. FUQUA. OK.

Mr. Tribble, thank you for coming today. We would be pleased to hear your testimony.

[The biographical sketch of Mr. Tribble follows:]

U.S. Department of Energy
Assistant Secretary for
Congressional, Intergovernmental
and Public Affairs
Office of Public Affairs
Washington, D.C. 20585
202 252 5644

BIOGRAPHY

JOSEPH J. TRIBBLE

Joseph J. Tribble was confirmed Assistant Secretary for Conservation and Renewable Energy, U.S. Department of Energy (DOE) on May 14, 1981.

Prior to his current appointment, Mr. Tribble was Energy Coordinator for the Unbleached Division of Union Camp Corporation. In that position, he was responsible for energy management for the firm's unbleached paper mills in Montgomery, Alabama; Monroe, Michigan; and in Savannah, Georgia.

Mr. Tribble received a degree in mechanical engineering from Georgia Institute of Technology in 1942.

Mr. Tribble has been an active leader in the Republican Party since 1960, serving one term as State Chairman of the Republican Party of Georgia and two terms as State Senator (the first Republican State Senator from southeast Georgia in this century). He was a Delegate, Member of the Platform Committee, and Member of the Energy Subcommittee of the Republican National Conventions of 1976 and 1980. He was Chairman of the 1980 Reagan for President Campaign in the First Congressional District of Georgia.

At the time of his appointment he was serving as Chairman of the Administrative Board of the Wesley Monumental United Methodist Church in Savannah.

November 1982

STATEMENT OF JOSEPH J. TRIBBLE, ASSISTANT SECRETARY, CONSERVATION AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY, ACCOMPANIED BY JAMES S. KANE, DEPUTY DIRECTOR, OFFICE OF ENERGY RESEARCH

Mr. TRIBBLE. Mr. Chairman, we appreciate the opportunity to participate in this hearing today on the subject of indoor air quality. In your letter of invitation, you asked that we review the research activities carried out by the Department of Energy and also that we discuss our future plans.

The Department of Energy has been involved to some degree in indoor air quality research since its inception. A predecessor agency, the Energy Research and Development Administration, or ERDA, began research in this area in the 1977 timeframe, largely in response to inquiries from the public on potential problems associated with tightening up houses and commercial buildings in response to higher energy prices.

At that time the American Society of Heating, Refrigerating and Air Conditioning Engineers, ASHRAE, had guidelines for operators and designers of commercial buildings, but had no ventilation standards for residences. Initial research activities focused on determining minimum ventilation requirements to achieve acceptable indoor air quality.

Over the last 5 or 6 years, the Department has sponsored research in a variety of areas relating to indoor air quality. Low-cost portable instrumentation has been developed for measuring levels of pollutants and infiltration rates in buildings. A residential infiltration model has been developed and published in ASHRAE's "Handbook of Fundamentals." Laboratory testing of residential heat exchanger concepts has been conducted and will be completed with 1983 funding. Once completed, we should be able to provide homeowners with an indication of the cost effectiveness of installing such devices.

New measurement techniques have been developed for formaldehyde, radon, carbon monoxide, water vapor, and ventilation. Private companies have formed to market some of these measurement techniques. Building materials have been examined for their radon emanation rate, with the finding that soil is the principal source of radon.

DOE, of course, is only one of the players in this area. ASHRAE has been setting ventilation guidelines and standards for nearly a hundred years. The Gas Research Institute and the Electric Power Research Institute have active research programs in indoor air quality.

Within the U.S. Government, a number of agencies have some involvement in indoor air quality concerns. The Consumer Product Safety Commission monitors and, where necessary, regulates impacts on indoor air quality of specific products, such as kerosene heaters, foam insulation, and so forth.

The Department of Housing and Urban Development insures that health care facilities and homes covered by Federal mortgage guarantee programs meet minimum property standards. The Environmental Protection Agency, also represented at this hearing, conducts total exposure assessments and monitors environmental impacts of pesticides used around homes. In order to better coordinate Federal efforts in this area, and to insure that all involved agencies are aware of activities being conducted by other agencies, DOE and EPA cochair an interagency Coordinating Working Group on Indoor Air Quality. Membership in the working group includes Defense, HUD, the Consumer Product Safety Commission, HHS, and the National Bureau of Standards.

As the work going on within conservation and renewable energy has drawn to a close, we have attempted to better define an appropriate role for the Department in this broad spectrum of activity. We are concerned with indoor air quality primarily because of the ancillary effects of efforts to reduce energy consumption in buildings. As efforts to reduce infiltration become more and more successful, the potential for buildup of dangerous concentrations of pollution causes concern. Ventilation standards determined by ASHRAE establish levels of ventilation which would prevent the buildup of dangerous concentrations of pollutants.

It is instructive at this point to determine how much energy might be saved by reducing the ventilation in a residence. For a residence of 1,500 square feet of heating area, in a climate similar to that of Washington, D.C., the energy saved as a result of reducing the volume of air heated by reducing ventilation from half an air change an hour to a quarter of an air change an hour has been calculated to amount to, on the order of 2,100 Btu's per hour. Given the D.C. climate and a fuel cost of $8 per million Btu, and an equipment efficiency of 70 percent, the saved fuel cost would be approximately $5.50 per month for heating, as an annual average.

Incidence of indoor air pollution at dangerous levels is very site specific, even building specific. In fact, we know—and it has been mentioned this morning—that it is occupant specific in some cases—pets, plants, smoke, foodstuffs, et cetera. One aspect of our research program has been to develop sensors so that determinations can be made without great expense in buildings where there is a suspicion of pollution levels above "safe" levels. We have already discussed the work DOE has done in this area.

We are also aware of research and development funded by the New York State Energy Research and Development Agency, Niagara Mohawk Power Co., and others, to continue research, field test and validate these and other sensors. The Department's sensor development program has already been funded and should be completed with 1983 resources.

We have also initiated a program, jointly funded by EPRI and GRI, to establish a data base on indoor air pollutants. We will continue to monitor this data to determine if future research is warranted. Additionally, we have commissioned a program to map geographic areas for potentially high radon concentrations across the country, have developed a passive radon sampler—although the sampler most widely used at this time was developed entirely by the private sector—and plan to publish a technical bulletin to illustrate how existing and new construction can reduce the risks of this potential pollutant.

The Department has also conducted research in other indoor air quality areas, when such areas are specifically energy-related, for example, building materials used to improve the energy efficiency of buildings. We have completed work on urea-formaldehyde foam insulation and have established a laboratory at Lawrence Berkeley Laboratory for testing of organic compounds contained in, and emitted by, building materials. The Office of Energy Research is also conducting research on formaldehyde and nonasbestos insulation fibers.

Another energy-related area is that of infiltration. DOE has done extensive work in this area for residential buildings. A residential infiltration model has been developed and validated. Air leakage sites within the building have been identified and instrumentation has been developed to measure infiltration rates. The last major energy-related area is that of heating, cooling and cooking equipment. DOE has conducted tests on emissions resulting from wood stoves, gas stoves, and kerosene heaters.

The Department has thus completed, or has in progress, research and development activities addressing the major energy-related sources of indoor air pollution. Nonenergy related sources are being addressed by others. A number of studies are underway by EPRI, GRI and others, to determine where there are gaps remaining in our knowledge base on indoor air quality.

While we feel it is appropriate for Federal agencies to monitor potential health hazards, and to assist the private sector in minimizing these hazards when health risks do occur, we feel it would be most prudent to await the outcome of the ongoing studies before planning any additional indoor air quality research within DOE, other than that being done by the Office of Energy Research.

Certainly this hearing is a very valuable adjunct to this subject, because out of it will come recommendations of research that will be both needed and prudent.

Mr. Chairman, this concludes our formal testimony. We would be pleased to attempt to answer questions you or the subcommittee members may have.

[The prepared statement of Mr. Tribble follows, also handout of Dr. James S. Kane:]

STATEMENT OF

JOSEPH J. TRIBBLE

ASSISTANT SECRETARY, CONSERVATION AND RENEWABLE ENERGY

Mr. Chairmen:

We appreciate the opportunity to participate in this hearing today on the subject of indoor air quality. In your letter of invitation, you asked that we review the research activities carried out by the Department of Energy and also that we discuss our future plans.

As you are probably already aware, the Department has been involved to some degree in indoor air quality research since its inception. A predecessor agency, the Energy Research and Development Administration or ERDA, began research in this area in the 1977 timeframe, largely in response to inquiries from the public on potential problems associated with tightening up houses and commercial buildings in response to higher energy prices. At that time, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) had guidelines for operators and designers of commercial buildings, but had no ventilation standards for residences. Initial research activities focused on determining minimum ventilation requirements to achieve acceptable indoor air quality.

Over the last five or six years, the Department has sponsored research in a variety of areas relating to indoor air quality. Low-cost portable instrumentation has been developed for measuring levels of pollutants and infiltration rates in buildings. A residential infiltration model has been developed and published in ASHRAE's Handbook of Fundamentals. Laboratory testing of residential heat exchanger concepts has been conducted and will be completed with FY 1983 funding. Once completed, we should be able to provide homeowners with an indication of the cost effectiveness of installing such devices. New measurement techniques have been developed for formaldehyde, radon, carbon monoxide, water vapor and ventilation. Private companies have formed to market some of these measurement techniques. Building materials have been examined for their radon emanation rate, with the finding that soil is the principal source of radon.

In FY 1983 a[illegible], DOE work will be completed on a field validation of CO passive monitors, a field study of formaldehyde control, a study of energy recovery for exhaust air (co-funded with Bonneville Power Administration), radon control efforts, radon transport through crawl spaces, ventilation efficiency in large buildings, and a lab study on air washing for formaldehyde control. As an outgrowth of radon health effects studies related to uranium mining and milling, a modest research program is being maintained in the Office of Energy Research to investigate radon migration pathways into structures, to determine radon daughter particulate size distributions and plate-out rates, and to examine environmental influences on radon daughter concentrations. Also, an effort to assess the significance of these parameters with rspect to potential health effects is continuing.

DOE is, of course, only one of the players in this area. ASHRAE has been setting ventilation guidelines and standards for nearly one hundred years. The Gas Research Institue (GRI) and the Electric Power Research Institute (EPRI) have active research programs in indoor air quality. I would draw the Committee's attention to two recent International Energy Agency publications: Air Infiltration Control in Housing: A Guide to International Practices and Guiding Experiments Concerning Design of Experiment Instrumentation and Measuring Techniques. These reports demonstrate the level of interest in indoor air quality issues worldwide and the extensive work being undertaken in response to this interest. Within the U.S. Government, a number of agencies have some involvement in indoor air quality concerns. The Consumer Product Safety Commission monitors, and where necessary, regulates impacts on indoor air quality of specific products, such as kerosene heaters, foam insulation, etc. The Department of Housing and Urban Development (HUD) ensures that health care facilities and homes covered by Federal mortgage guarantee programs meet minimum property standards. The Environmental Protection Agency (EPA), also represented at this hearing, conducts total exposure assessments and monitors environmental impacts of pesticides used around homes. In order to better coordinate Federal efforts in this area, and to ensure that all involved agencies are aware of activities being conducted by other agencies, DOE and EPA co-chair an interagency Coordinating Working Group on Indoor Air Quality. Membership in the working group includes Defense, HUD, CPSC, HHS and the National Bureau of Standards at Commerce.

As the work going on within Conservation and Renewable Energy has drawn to a close, we have attempted to better define an appropriate role for the Department in this broad spectrum of activity. We are concerned with indoor air quality primarily because of the ancillary effects of efforts to reduce energy consumption in buildings. As efforts to reduce infiltration become more and more successful, the potential for buildup of dangerous concentrations of pollution causes concern. Ventilation standards determined by ASHRAE establish levels of ventilation which would prevent the buildup of dangerous concentrations of pollutants. In the residential area, 100 cubic feet per minute for kitchens, 50 cubic feet per minute for bathrooms and 10 cubic feet per minute for other occupied spaces is considered adequate to avoid excessive concentrations of pollutants. This could vary from 0.5 to 1 air change per hour. By comparison, the "typical" home today averages 0.75 to 1 air change per hour. In the commercial area, application of ASHRAE standards for commercial buildings results in roughly 0.5 air change per hour in a typical building under normal operations.

It is instructive at this point to determine how much energy might be saved by reducing the ventilation in a residence below this level for a residence of 1500 square feet of heating area in a climate similar to that in Washington, DC. The energy saved as a result of reducing the volume of air heated, for example, by reducing ventilation from 0.5 air changes per hour to 0.25 air changes per hour, would amount to 2,160 BTU/hour. Given the DC climate and a fuel cost of $8.00/MBTU at 70 percent equipment efficiency, the saved fuel cost would be approximately $5.50 per month for heating, as an annual average, obviously only a minor fraction of the total heating costs.

Incidence of indoor air pollution at dangerous levels is very site-specific, even building-specific. In fact, we know that it is occupant-specific in some cases (i.e., pets, plants, smoke, foodstuffs, furnishings, etc.). One aspect of our research program has been to develop sensors so that determinations can be made without expense in buildings where there is a suspicion of pollution levels above "safe" levels. We have already discussed the work DOE has done in this area. We are also aware of research and development funded by the New York State Energy Research and Development Agency, Niagara Mohawk Power Company and others to continue to research, field test and validate these and other sensors. The Department's sensor development program has already been funded and should be completed with FY 1983 resources.

We have also initiated a program, jointly funded by EPRI and GRI, to establish a data base on indoor air pollutants. We will continue to monitor this data to determine if future research is warranted. Additionally, we have commissioned a program to map geographic areas for potentially high radon concentrations across the country, have developed a passive radon sampler (although the sampler most widely used at this time was developed entirely by the private sector), and plan to publish a technical bulletin to illustrate how existing and new construction can reduce the risks of this potential pollutant.

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The Department has thus completed, or has in progress, research and development activities addressing the major energy-related sources of indoor air pollution. Non-energy-related sources are being, or should be addressed by others. A number of studies are underway--by EPRI, GRI and others--to determine where there are gaps remaining in our knowledge base on indoor air quality. While this Administration feels it appropriate for Federal agencies to monitor potential health hazards, and to assist the private sector in minimizing these hazards when health risks occur, we feel it would be most prudent to await the outcome of the ongoing studies before planning any additional indoor air quality research, other than that being done by the Office of Energy Research.

Mr. Chairmen, this concludes our formal testimony. We would be pleased to try to answer any question you or other members of the Subcommittee may have.

Handout of James S. Kane
Deputy Director
Office of Energy Research
Department of Energy
Subcommittee on Energy Development and Applications
and
Subcommittee on Natural Resources, Agriculture Research
and Environment
House Science and Technology Committee
August 3, 1983

Objectives:

In recent years, it has become widely recognized that the broad-scale introduction of conservation-related technology in U.S. residential and commercial buildings may increase the exposure of the population to a number of potentially harmful pollutants. As part of its mission to evaluate the possible health and environmental effects associated with emerging energy technologies and conservation options, OER's Office of Health and Environmental Research (OHER) has initiated studies to characterize certain key indoor air pollutants and identify their possible health effects. The OHER program is limited in scope, and based on the available expertise in radon and radon-daughter research and inhalation toxicology. The program is further defined to include only those indoor pollutants that are not addressed adequately by research programs carried out by other agencies. The characterization studies, primarily of the radioactive gas radon, are aimed at determining the sources and pathways of exposure so that cost-effective control technology can be developed, and to aid in the interpretation of health effects findings, if any. The health effects studies are designed to determine the kind and degree of acute and chronic respiratory injury and the levels at which these occur. These results will be applied to the assessment of the possible health consequences in human populations from the use of advanced conservation measures, and to assist in the identification of optimal control strategies.

Programs:

In the development of OHER's programs, coordination with DOE's office of Conservation and Renewable Energy and other Federal agencies has be[illegible] achieved through the activities of the Interagency Research Group on Indoor Air Quality. The major program themes and funding levels for FY 1983 and FY 1984 are as follows:

Physical and Technological Programs:

To date, these programs have concentrated on radon characterization, i.e., on investigations of radon sources and modes of entry into buildings, on radon and radon decay product concentrations in indoor air under various environmental conditions, and on the properties of the inhaled particulates to which radon decay products are attached. Emphasis has been placed on the development, evaluation, and standardization of measurement techniques. In the future, radon characterization studies will be continued, and consideration will be given to the initiation of studies of airborne organic chemicals in the indoor environment. Budget levels are $750,000 for FY 1983 and $828,000 for FY 1984.

Human Health Effects Studies

The program in human health effects, taking into account each class of pollutants characterized as to source and concentration encountered, emphasizes the health and exposure implications of key pollutants. The research on radon and radon-daughter products is emphasizing the exposure distribution and health risk assessment and is evaluating the potential for epidemiology studies among the general U.S. population. New research initiatives on organic pollutants will examine the potential for correlating indoor organic pollutants with possible acute irritant effects. A future study of normal and asthmatic subjects is planned to explore the acute effects of formaldehyde exposure. Budget levels are $260,000 for FY 1983 and $488,000 for FY 1984.

Health Effects Research Program

This research is designed to detect, understand, and quantify health risks that may be associated with human exposures to toxic gases, vapors, or particles present in indoor air. Particle deposition, retention, and translocation as well as induced biological responses are being determined in animals exposed to small glass fibers via the respiratory tract. For comparative purposes, similar studies are performed with tumorigenic asbestos fibers. Results from this study will determine if manmade glass fibers, a component of certain insulation materials, present a risk of lung cancer, and help to elucidate mechanisms of fiber tumorigenesis. Another study defines the metabolism and biological effects of inhaled formaldehyde, a common component of indoor air. Emphasis centers on determining the extent to which formaldehyde vapor is bound to the surface of airborne indoor particles and the extent to which particle-bound formaldehyde may pose a cancer risk in the deep lung. Effects of low levels of nitrogen dioxide on lung development in young animals are also being evaluated. Future studies will include long-term low-level exposures to evaluate risks of chronic lung disease. Budget levels are $270,000 for FY 1983 and $280,000 for FY 1984.

Handout for 8/3/83
HST Hearing

DOE OFFICE OF ENERGY RESEARCH

Programs Related to Indoor Air Quality

Objectives:

In recent years, it has become widely recognized that the broad-scale introduction of conservation-related technology in U.S. residential and commercial buildings may increase the exposure of the population to a number of potentially harmful pollutants. As part of its mission to evaluate the possible health and environmental effects associated with emerging energy technologies and conservation options, OER's Office of Health and Environmental Research (OHER) has initiated studies to characterize certain key indoor air pollutants and identify their possible health effects. The OHER program is limited in scope, and based on the available expertise in radon and radon-daughter research and inhalation toxicology. The program is further defined to include only those indoor pollutants that are not addressed adequately by research programs carried out by other agencies. The characterization studies, primarily of the radioactive gas radon, are aimed at determining the sources and pathways of exposure so that cost-effective control technology can be developed, and to aid in the interpretation of health effects findings, if any. The health effects studies are designed to determine the kind and degree of acute and chronic respiratory injury and the levels at which these occur. These results will be applied to the assessment of the possible health consequences in human populations from the use of advanced conservation measures, and to assist in the identification of optimal control strategies.

Programs:

In the development of OHER's programs, coordination with DOE's office of Conservation and Renewable Energy and other Federal agencies has been achieved through the activities of the Interagency Research Group on Indoor Air Quality. The major program themes and funding levels for FY 1983 and FY 1984 are as follows:

Physical and Technological Programs:

To date, these programs have concentrated on radon characterization, i.e., on investigations of radon sources and modes of entry into buildings, on radon and radon decay product concentrations in indoor air under various environmental conditions, and on the properties of the inhaled particulates to which radon decay products are attached. Emphasis has been placed on the development, evaluation, and standardization of measurement techniques. In the future, radon characterization studies will be continued, and consideration will be given to the initiation of studies of airborne organic chemicals in the indoor environment. Budget levels are $750,000 for FY 1983 and $828,000 for FY 1984.

Human Health Effects Studies

The program in human health effects, taking into account each class of pollutants characterized as to source and concentration encountered, emphasizes the health and exposure implications of key pollutants. The research on radon and radon-daughter products is emphasizing the exposure distribution and health risk assessment and is evaluating the potential for epidemiology studies among the general U.S. population. New research initiatives on organic pollutants will examine the potential for correlating indoor organic pollutants with possible acute irritant effects. A future study of normal and asthmatic subjects is planned to explore the acute effects of formaldehyde exposure. Budget levels are $260,000 for FY 1983 and $488,000 for FY 1984.

Health Effects Research Program

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Mr. **Fuqua**. Thank you, Mr. Tribble.

You mentioned about jointly funding projects with EPRI and GRI to establish a data base. What is the amount of money involved in that research?

Mr. **Tribble**. I'm under the impression that it's on the order of $50,000.

Mr. **Fuqua**. For each one or total?

Mr. **Tribble**. For each one.

Mr. **Fuqua**. And how much are they putting up?

Mr. **Tribble**. My understanding is that it's 50-50.

Mr. **Fuqua**. You also mentioned the completed work on the urea-formaldehyde foam insulation and a laboratory established at Lawrence Berkeley. Is it in operation?

Mr. **Tribble**. I'm sorry, I will have to answer that one for the record. I do not know that.

[The material follows:]

The laboratory at Lawrence Berkeley is currently in operation.

Mr. **Fuqua**. It is my understanding it won't be able to operate. Can Dr. Kane give us any assistance on that?

Dr. **Kane**. No; I really can't. I can describe only the activities that Energy Research is doing at the Lawrence Berkeley Laboratory.

Mr. **Fuqua**. But you're not funding—Energy Research is not funding that particular research?

Dr. **Kane**. Not the exact topic you alluded to, that's correct, the urea-formaldehyde.

Mr. **Fuqua**. We were told yesterday that there was a large number of projects on indoor air quality at the Berkeley Lab and that they had been canceled. Could you elaborate on the reason for that, or is that an accurate statement?

Mr. **Tribble**. I think it would be in order for me to explain to the committee a situation that has existed that we think we have resolved. The programs that were mentioned were not necessarily canceled because they had never been authorized.

In the review of the work that we were going to do, and funding 1983 activities, we went through the proposed activities and some of them were questioned during that review. We were, unfortunately, unable to get the details of just what was to be done in here, from headquarters. We felt that we needed more details of the individual projects that were going to be funded. Inasmuch as we were unable to get that information here, we did—I did—hold up funding of a number of those projects until I could get a better understanding of what we were doing.

Mr. **Fuqua**. When did that occur?

Mr. **Tribble**. That was, I believe, in May. And so I scheduled a meeting, a visit to LBL. I went out and discussed the problems with Dr. Shirley. There were funding problems as well as problems associated with the activities involved. We worked together in a way that would avoid having LBL have to lay off or give notice to any of their people, but which would also give us an opportunity to review the actions that we were taking and perhaps redirect some of the work that had been originally proposed and agreed upon early by headquarters staff.

In that visit, I got a much better insight on the work that was going on there. Some of the things that were going on that had been approved orally, we decided yes, go ahead with, and on the other hand, we are still working together to redirect some of the projects.

We must say all the time we did this in a way that we would not cause layoffs and we would not lose the expertise that exists at LBL in this field, recognizing full well that the Congress may not accept our proposals for budget in 1984 and we would not want to create a situation where we would lose the valuable people that we have there.

This is—we have in these operations something that is called a GSO account, which is an amount of money that permits them to continue to operate over a period of—a minimum of 90 days beyond the end of the fiscal year, to accommodate this kind of eventuality. And we have worked together so that this will not be a problem.

Mr. **FUQUA**. How much was included in the Interior appropriation for this type of activities in the fiscal year 1983 budget?

Mr. **TRIBBLE**. My recollection is on the order of $950,000.

Mr. **FUQUA**. And did not they have an explicit statement directing that DOE maintain the existing research team in research programs at that particular laboratory?

Mr. **TRIBBLE**. If you suggest that they did, I feel sure that is the case and we have done so.

Mr. **FUQUA**. That is my understanding. But 7 months into the fiscal year, you started canceling programs.

Mr. **TRIBBLE**. I must repeat, we had never authorized the projects and we were merely redirecting some of the activities.

Mr. **FUQUA**. Well, it is my understanding that some of the people in DOE, your subordinates, had recommended approval of the projects.

Mr. **TRIBBLE**. I think that's right. But those were the same people who could not give me the details of what was going to be done.

Mr. **FUQUA**. It is also my understanding that the Interior appropriation for fiscal year 1984 has $1.6 million for indoor air quality research, so that as far as the argument you're uncertain about congressional support, it appears that that's considerably more than the 950, it is considerably more for those programs.

Mr. **TRIBBLE**. That's right. If that is the final word on the 1984, that certainly will be true.

Mr. **FUQUA**. They're in conference and that figure could be subject—but I doubt that it would be eliminated.

Mr. **TRIBBLE**. Right.

Mr. **FUQUA**. It could be adjusted up or down. I don't recall what the Senate did.

Do you intend to follow that mandate, also, or—

Mr. **TRIBBLE**. Certainly. Yes, if the money is allocated and appropriated, we certainly will do the best we know to find an appropriate way to handle it.

Mr. **FUQUA**. It appears, in the information that we have received, that in several cases—and I quote—"in building materials emissions—" it says—

> does not have commitment for support beyond this calendar year; residential combustion appliances is not now supported by DOE/CE. Passive samplers, DOE/CE

support is being closed out. Control techniques, no commitment for funding from DOE/CE beyond fiscal year 1983. Survey design, no current funding. Indoor air quality modeling, no current funding. Indoor organic pollutants, no current funding.

Now, are these statements true?

Mr. **Tribble**. Yes; they are true, in that in our 1984 request we did not ask for money to continue these activities.

Mr. **Fuqua**. Well, would you classify this as a closing down mode of the Lawrence Berkeley Lab activities in these areas?

Mr. **Tribble**. Certainly it would be a diminishing of that, and the only activity that would be remaining would be the completion of the programs that were funded with 1983 dollars.

Mr. **Fuqua**. Has the quality of their work been below standards?

Mr. **Tribble**. No.

Mr. **Fuqua**. Why would these programs be terminated, then, or closed down?

Mr. **Tribble**. Various reasons. I don't know the details of the individual programs that you mentioned. But some of them may very well be in the province of the private sector; some of them may very well be in the province of other agencies within the Federal Government. Those particular ones that you mentioned, as we went through I had the impression that they fell in those categories as you read them.

Mr. **Fuqua**. You indicated earlier that you made these decisions yourself——

Mr. **Tribble**. That's right.

Mr. **Fuqua** [continuing]. Or your staff, but you don't know why you made these decisions?

Mr. **Tribble**. Wait a minute. I must have misunderstood your question.

Mr. **Fuqua**. You were saying you really didn't know what were these programs that I enumerated, were being funded by other agencies or properly in the private sector or other——

Mr. **Tribble**. You read a list of them. If you would give me one by one, I would be glad to try to respond.

Mr. **Fuqua**. Well, the first one was building materials emission, and a quote from the DOE says it does not have a commitment for support beyond this calendar year.

Mr. **Tribble**. Yes. In my opinion, that perhaps is more the responsibility of the Consumer Product Safety Commission, to evaluate products and emissions from products.

Mr. **Fuqua**. Have you talked with them about——

Mr. **Tribble**. No, I have not.

Mr. **Fuqua**. This would be like the lab that was built, the urea-formaldehyde lab, or to test that at the Berkeley Lab. Would you want to transfer that to Consumer Product, or what was the purpose of building the lab in the first place?

Mr. **Tribble**. Certainly, if the work were continued and funded by Consumer Products, the same facilities could be used.

Mr. **Fuqua**. But why was the lab put there in the first place?

Mr. **Tribble**. It was done with prior, certainly a prior decision was made that it was necessary. I'm sorry, I don't——

Mr. **Fuqua**. But the Congress had appropriated money, that we think this is important work and we addressed that to the Department of Energy, specifically to your department.

Mr. TRIBBLE. It is my understanding that some of the other agencies are doing work in this field. Is not—I'm sorry, I don't know, but I would think the Consumer Product Safety Commission is, in fact, doing work on urea-formaldehyde.

Mr. FUQUA. They may be, but I don't think to the extent, nor are they equipped with facilities and the technical know how as the Department of Energy is as at their lab that is operated at Berkeley.

Let's go to the next one. You said passive samplers are being closed out.

Mr. TRIBBLE. Yes; most of the passive samplers will be developed—have been developed or will be completed with 1983 funding. As a matter of fact, some of those are available on the market quite readily.

Mr. FUQUA. It said control techniques, no commitment of funding beyond 1983, so I guess that's being closed out.

Mr. TRIBBLE. I presume we're speaking of controlled ventilation, control techniques, and we have a number of techniques that are available to us, of course. We have done a good bit of work on evaluating air-to-air heat exchangers that will be one method of resolving indoor air pollution problems. The control techniques certainly will be a function of the mechanical equipment that is installed for heating and ventilating and air conditioning. We don't know of other control techniques that we should be working on.

Mr. FUQUA. Mr. Tribble, yesterday we had a series of witnesses, only of which one was from Berkeley. The rest were independent, from various parts of the country and varying backgrounds, but knowledgeable in these areas. I think if there was one thing that was—while there were a lot of things of unanimity, but the one thing that they stressed was the fact that we need one place to do the data base and collect all this information so that it can be analyzed by other labs and other researchers around the country. They all said about the only place that had the capability, that had been established, and was functioning in a very creditable manner, was the Berkeley Lab. Now we find we are diminishing or destroying our ability to get this broad data base so that it can be analyzed, and all of these issues that we have been discussing earlier this morning and now can be operated.

I think that is why Congress felt strongly about that, not only in authorizing funds, but also in appropriating the funds, of $950,000 last year, it passed the House this year of $1.6 million, and even if that is cut a third, it is still more than last year. So I think there is a great deal of interest among the people that extract the money from the taxpayers and appropriate it that this is a very important area.

Here we find that DOE is thumbing its nose at the mandate of Congress and the concerns that we have, particularly when there is not this capability—and neither should it be duplicated in a lot of different places; that would be very expensive. But if this lab at Berkeley seems to be the most—or has the most unique capability of performing this very valuable collection of data, that the scientific community tells us is very much needed.

Mr. TRIBBLE. We would certainly agree that the accumulation of the data base is important. We have initiated through LBL a program of attempting to relate areas of the country that may have high radon levels with a program that has been conducted earlier during—I'm sorry I don't know the name of it, if you'll bear—it's the national uranium resource evaluation program.

We are attempting to determine whether there is a correlation that can be drawn from that data that would tell us where the areas are that we should be the most concerned with. This would be one of the first steps in accumulating a good data base. Of course, one approach could be to attempt to survey the entire United States, but that would be terribly expensive, and considering the many variabilities that would have to be considered and considering the site specifics, the building specifics, we don't think that would be money well spent. But moving in the direction that we are, we would expect to go forward with the accumulation of the data.

I mentioned earlier there is data being gathered by a number of other organizations, and we agree with you, that it should be compiled in a data base so that it would be available because we think this is one of the important aspects of solving the problem, particularly as it relates to radon, which is perhaps the most important, most insidious of the indoor pollutants.

Mr. **Fuqua**. Well, that is one, and it is very important, but there is also nitrogen oxide that is produced. One of the things that has been of concern to me personally is the impact of houses later being built over sanitary landfills. Many times the growth areas of communities take them out, to where at one time had been sanitary landfills. What impact does that have on people and what type of housing should they have?

You don't have to go all over the country to do that, but you can do some work in that in various selected sites to get a data base for that type. If you're talking about granite and other types of geological formations, certainly that is very, very helpful, but there are other types of pollutants besides just radon that we are concerned about, not to minimize the impact of it, either.

Mr. **Tribble**. In that regard, I would suggest that a public information program would be very valuable to acquaint the general public with the problems that can arise as infiltration is diminished, because I feel sure that the general public is not aware that they may have a problem.

There are a number of vehicles that do exist. I am sure you are familiar with the fliers that many times are included in utility bills that suggest conservation measures and things of this nature. This would be one way that seems to me to introduce the potential problem to the general public, and if they then are aware of the fact that they may in fact live over a previous landfill, and if they simply know they could have a problem by virtue of that fact, this, to me, is a beginning then of establishing a consciousness with which we can go forward and solve the problem.

Mr. **Fuqua**. I agree with you completely, but until we know what the problems are and have an analysis of that, I think we could be passing out information that may not be accurate. We may create alarming situations. For instance, we discussed yesterday the impacts of wood-burning stoves and open fireplaces. I happened to grow up with that type of home and I was glad——

Mr. **Tribble**. So did I.

Mr. **Fuqua** [continuing]. It was not very air tight, either.

Mr. **Tribble**. That's right. We didn't have to worry about infiltration, did we?

Mr. **Fuqua**. I feel a little safer. But as more and more people are looking at that possibility, we should not put out misinformation or alarm people unnecessarily. They're alarmed enough about things that go on. That's the purpose of what we're talking about of this whole scenario, is that we can find and have accurate information and have a better understanding of the impact of these pollutants, what does it cause, does it cause cancer or does it cause emphezema or does it cause other types of symptoms or diseases that people may have. What does it do to elderly people, what does it do to young people, what does it do to pregnancies? All of these things we are finding more and more in other areas are influenced by the lifestyle or the intake of food or other things into the body. It could also be with air or other types of things.

I don't know the answer, and that's why we're trying to find this out and why we think this program is so important, to try to get the data base and get it moving so that we can have a better understanding and more knowledge about the effects and how, if that is an impact—you can't relocate everybody in the State of Maine, and neither would they want to. But how can they make sure the next generation of homes and other things, and even the ones they live in now, can be more safe than—maybe and maybe not—they are today because of the granite or extreme amount of granite that they have in that State. But this is true of other areas. That's the reason I think the Congress feels very strongly that this is a very imortant program.

Before I ask Mr. Ottinger, would you be willing to go back and relook at some of these things after our interest has been exhibited to you——

Mr. **Tribble**. Yes; I think it's a very appropriate thing to do. I think that the information that will come out of this hearing will be very helpful, and certainly we would do so.

Mr. **Fuqua**. I think, if they thought all the answers were known, that EPRI and GRI would probably not be participating in a project of that type. But I think——

Mr. **Tribble**. That's right.

Mr. **Fuqua** [continuing]. Even their interest at a modest amount of $50,000 is indicative of the fact that they recognize the concern of this. But it has also been replete, that probably the only place that you can get a full data base is probably through the Federal Government, and it is a Federal responsibility to try to collect all of this or participate in its collection and somebody being a leader to make sure that it is collected.

Mr. **Tribble**. Mr. Chairman, the $50,000 that I mentioned I believe is just a participation in one small project——

Mr. **Fuqua**. There's not a lot you can do with $50,000.

Mr. **Tribble**. No. But let me—I just picked up out of one of the trade publications a note that EPRI is spending $700,000 in a 2-year study of air infiltration rates, the effect of air infiltration rates, and on energy use and indoor air quality. So I would not want the record to imply that the $50,000 is all that EPRI is spending. They are, in fact, doing a great deal more.

Mr. FUQUA. EPRI and GRI are submitting written testimony to us of their activities in these areas, so I assume they will outline those activities.

Mr. Ottinger.

Mr. OTTINGER. Thank you, Mr. Chairman.

Mr. Tribble, I think you're trying to jerk us around again in your ideological warfare against programs you don't like. I have before me a series of project descriptions describing in great detail each of these programs that you zeroed out, dated February 3, 1983. There is one, for instance, on indoor air quality control techniques. It states the objectives, to evaluate energy performance, contaminant control capabilities, economic performance of techniques and concentration of contaminants, and the indoor air and access feasibility of new techniques for contaminant control. It states the problem is significant. It states what's going on in the private sector, research, what is not being done in the private sector that is important it be done, and the specific description of the project.

There is similar detailed project descriptions dated February 3, 1983, by DOE/CS, relating to concentrations of indoor pollutants, CIP data base, the same kind of analysis. Another one on radon, another one on passive samplers, specifically showing those areas in which passive samplers have been developed, the need for field testing of some of them, the need for development of new passive samplers and other cases, building materials emissions, again showing what the private sector is doing and what is needed to be done and will not be done if Lawrence Berkeley didn't do it, residential combustion appliances, the same thing and so forth.

You mean to say you didn't have these available to you when you made this decision?

Mr. TRIBBLE. I sure couldn't say that I had all that you listed.

Mr. OTTINGER. How come we can get them and you can't?

Mr. TRIBBLE. You've got a lot better pipeline into my organization than I have, I believe.

Mr. OTTINGER. These are projects, summaries that were submitted by the Berkeley program people within your department. But you say you didn't know anything about these individual project descriptions and analyses.

Mr. TRIBBLE. No; I didn't say I didn't know anything about them. I said I could not get the detail that I wanted from conversations with the people that I asked.

Mr. OTTINGER. Well, the Chairman just asked you about the passive samplers and you said that all the research that was being done was out in the private sector, and this shows the work that isn't being done.

Mr. TRIBBLE. No; I don't believe I said that. I said the work that is being done by the passive samplers will be completed with fiscal 1983 funding.

Mr. OTTINGER. Well, the scope of the work here hardly seems to make that true, and that wasn't the testimony of Mr. Nero when he testified yesterday.

Do you talk to each other in the Department?

Mr. **Tribble**. I don't believe you were here when I made an explanation of the problems that we had that originated that.

Mr. **Ottinger**. Well, I have been here since you started, listening with some incredulity.

Are you aware that your own department held a conference at Carmel Valley, a workshop——

Mr. **Tribble**. I was there all the time.

Mr. **Ottinger**. And they went through and analyzed all these various programs and——

Mr. **Tribble**. I attended a workshop during the entire conference.

Mr. **Ottinger**. And weren't there conclusions that the work specified here is work that needed to be done by the Federal Government?

Mr. **Tribble**. The Carmel conference was a conference to determine what needed to be done, not just by the Federal Government, but by the entire research community, both private sector and Federal, and no delineation was made at that conference as to which should be the private sector's responsibility, or the Federal Government's responsibility.

Mr. **Ottinger**. That's not the indication I have.

Do you have—are you aware of the National Research Council's study of this matter, the National Academy of Sciences? Their conclusions were that definitive conclusions on the character of indoor air prevented by lack of systematic studies. The available data base has been generated by a series of pilot studies and does not fully characterize the variety of pollutants indoor environments and occupancy conditions and so forth. Studies explicitly addressing both long-term and episodic events have not been undertaken, and they go into some detail on that. Then their recommendations are that a stage assessment of the exposures to the general population of indoor pollutants and the effects of such exposures on health and welfare should be conducted by the Federal Government, in both residential and office buildings. They go on to tell what the various departments are doing, the critical role that the LBL program plays in this endeavor.

And seven, responsibility for conducting a well-coordinated investigation of the influence of building design and operational factors on concentration of pollutants in both residential and commercial facilities should rest with the Federal Government, assisted by appropriate professional and scientific organizations.

On what basis did you make your decision? The scientific community seems to be together, that this is important, it is important to health and safety. Are you just doing this because you didn't like the sound of it?

Mr. **Tribble**. No; that's not the reason.

Mr. **Ottinger**. What kind of scientific analysis can you present to us to show that these programs are not needed and are not going to be pursued unless the Federal Government pursues them?

Mr. **Tribble**. The Department of Energy is, of course, not the only agency of the Federal Government that's involved with this, and many of these aspects fall under the areas of responsibility of the other agencies.

Mr. **Ottinger**. You don't like to put anything on paper because it would indicate what kind of basis is being made for decisions which appear to us to be arbitrary. Here you have a good deal of scientific investigation saying one thing should be done, and you come in and say nothing and there's no scientific background at all for your decisions.

Don't you think we're entitled and the public is entitled to some kind of scientific basis for the decisions you make?

Mr. TRIBBLE. I am trying to explain the reason for the decisions I made at this hearing.

Mr. OTTINGER. Well, shall we go down one by one and find out what your scientific bases are for these various conclusions?

What about—well, here are the things that are canceled, but I wanted to get them in a better form here.

The radon survey is the first thing. That, I understand, is being carried forward, and the specific project description here says "We know already that information on radon is part of the National Airborne Radium Metric Reconnaissance data that is part of the recently completed national Uranium Resource Evaluation data base," which is the reason you said this thing didn't have to be pursued. As indicated by the memo, "This information needs to be combined with the USGS characterization of rock and soil types nationally. We will proceed to analyze these sources of information to determine their applicability to the overall effort of characterizing indoor radon nationally."

It is my understanding that the study that you have authorized is merely a literature search to unearth past research mapping of the United States for radon concentrations. That isn't what was called for in the project. How do you explain canceling out what the laboratory considers to be the essential part of the project?

Mr. TRIBBLE. What we are going forward with there is to determine whether or not this relationship between the geological formations and the information that was gathered during this flyover survey, and doing this as a preliminary step toward identifying areas where there may very well be cause of greater concern than in the entire area of the United States.

Mr. OTTINGER. What's the scientific basis for your making that determination?

Mr. TRIBBLE. I don't know that there is any scientific basis.

Mr. OTTINGER. On passive samplers that you indicate would be phased out, what is the scientific basis for that decision?

Mr. TRIBBLE. In many instances, these are judgment calls.

Mr. OTTINGER. What are they based on?

Mr. TRIBBLE. Based on opinions.

Mr. OTTINGER. With no backup at all to say that these things are or aren't needed.

These passive samplers are things that you put in the home and will continue to measure the various concentrations of pollutants. On what basis did you decide that that wasn't needed?

Mr. TRIBBLE. Because they are already available. As a matter of fact, in this room we have a sample that we could show you.

Mr. OTTINGER. In this detailed project description of February 3, that you should have had available to you, it says:

> Typically, passive samplers developed by the private sector have been designed for application to industrial hygiene sampling, i.e., with 8-hour sampling periods of concentrations that are high relative to residential concentrations. Many samplers suc-

> cessfully used in industrial hygiene sampling are not satisfactory at the lower concentrations and long sampling time is typically desired in sampling residential air. Longer sampling times are often desirable to average over a weekday, weekend activity cycle of occupants.

It goes into more and more detail and says the specific things that are needed.

Did you get any evidence to show that this information that was supplied to you by your own department wasn't accurate?

Mr. TRIBBLE. No; but in testimony yesterday it was pointed out that these devices are, in fact, available.

Mr. OTTINGER. But they're inadequate, according to this, to do the job that is needed for the residential market. And they go on to specifics, if you want them. I can read them to you for the first time, I guess.

> The 3M Company has developed a formaldehyde passive sampler for industrial hygiene and has recently marked this same device for sampling by lay people in residences. Because the maximum sampling interval of this sampler is 48 hours, the sampler has been passed over by the National Research Council of Canada in favor of the LBL-developed sampler. 3M is reportedly reconfiguring their sampler for suitability in sampling residential air.

It goes on to discuss each one of these individual private sector things and the things that still need to be done.

Are you aware of all this work that was done by your own department?

Mr. TRIBBLE. I'm aware of most of it.

Mr. OTTINGER. Well, on what basis, then, did you decide that this wasn't needed?

Mr. TRIBBLE. I think if we would follow the recommendations of all of the advisory groups that we have that make suggestions, we would——

Mr. OTTINGER. This isn't an advisory group——

Mr. TRIBBLE [continuing]. We would be spending a great deal more than we have available.

Mr. OTTINGER. This isn't an advisory group. This is your own department. And it was approved by your own staff. You just decided not to do it, and I want to know on what basis you decided not to do it.

Mr. TRIBBLE. Because at the time when I inquired I was not satisfied with the explanation of the details of the projects that were going to be done.

Mr. OTTINGER. What weren't you satisfied about in terms of passive sampling?

Mr. TRIBBLE. I was not satisfied that there was additional work needed that had to be done by the Federal Government, in view of the existence of the number of passive samplers that are available.

Mr. OTTINGER. Well, that's—the witnesses yesterday testified on the need for passive samplers for other types of contaminants that aren't being developed in the private sector. Are you familiar with their testimony?

Mr. TRIBBLE. I'm sorry, I didn't have an opportunity to read all the testimony that was presented yesterday before today, no.

Mr. OTTINGER. Here is one in your own department.

> Although it is unlikely that a passive sampler for suspended particles can be developed, the plan for the development of a small, portable sample for respiratory particles is similar to the development of passive samplers. Efforts will focus on se-

lection and fabrication of components for minimum size, weight, expense, servicing requirements and power requirements. We will seek co-funding for development of the CO_2 passive sampler and particulate sampler.

There's one that isn't available.

Why did you cancel that out?

Mr. **Tribble**. I guess I just didn't see any need for it, or I didn't think it was our responsibility to develop it.

Mr. **Ottinger**. Well, whose responsibility is it?

Mr. **Tribble**. Well, I don't guess that's my prerogative to say.

Mr. **Ottinger**. I see. Do you have any knowledge at all that anybody else is doing the work?

Mr. **Tribble**. Not any detailed knowledge, no.

Mr. **Ottinger**. According to a monthly report we received on the rate of spending for the conservation and solar programs, you had obligated less than 70 percent of the funds authorized for building sciences by June of 1983. That is despite the specific direction of the Interior Appropriations Committee, that the full amount be spent.

Why are you cutting back on the activities of indoor air quality if you can't spend the rest of the money in the building sciences area?

Mr. **Tribble**. I explained that in the early part of the hearing, but actually at the end of June 30 the amount that had been sent to the procurement office in that area was 79 percent, and by the middle of July it had reached 87 percent.

Mr. **Ottinger**. How do you coordinate research sponsored by your office with that sponsored by the Department of Energy's Office of Health and Environmental Research in indoor air quality?

Mr. **Tribble**. The Office of Energy Research is primarily concerned with more basic research and determining the health effects, and we are not involved with the health effects. We do not have any overlapping there.

Mr. **Ottinger**. Is there any coordination with what they're doing, because——

Mr. **Tribble**. We certainly know what each other is doing and we are not overlapping. I think that is the main objective of the coordination. They're doing work in a particular area and we are doing work in a different area.

Mr. **Ottinger**. One of the tasks proposed by the Lawrence Berkeley Laboratory for fiscal year 1983 involved building material emissions and had as its objective "to measure emissions from selected building materials and correlate these emissions with concentrations of organic contaminants."

You indicated to the Chairman that the reason for not pursuing these building materials emissions was because EPRI was doing it?

Mr. **Tribble**. No. I believe I indicated that I felt that that kind of work was more in the province of the Consumer Product Safety Commission.

Mr. **Ottinger**. I see. And you said you don't have any knowledge whether they are pursuing that work or not?

Mr. **Tribble**. Of course, I know that they have been doing research on a number of such things. I am not familiar with the details of their work.

Mr. OTTINGER. How is your decision consistent with the Carmel Valley workshop report recommendation that research be done to "characterize indoor contaminant sources and determine their physical and chemical properties"?

Mr. TRIBBLE. There again, the Carmel conference was to determine, on a very broad scale, not just into air quality but the kind of research that was needed in the entire building and energy research and development area. And it was for the purpose of determining generally what research is needed, not necessarily that that is needed, and as I mentioned earlier, not that that was needed by—to be done by the Federal Government or by any other particular entity, but generally an umbrella evaluation of the work that the people who were there felt needed to be done.

Mr. OTTINGER. But you didn't do any research to find out whether it was being done or what areas were not being addressed in the other Federal Government agencies or by the private sector before making your decision?

Mr. TRIBBLE. In the original planning that was done to set up the Carmel conference, which incidentally was cosponsored with HS&T and a number of other organizations, it was envisioned that we would have that conference. And the outgrowth of that was that others would be needed whereby we would consider the recommendations that would come out of the Carmel conference and the cosponsors could get together then and hopefully decide where would be the most appropriate place for the various research activities to be done.

That followup conference has not been held yet.

Mr. OTTINGER. Well, your own department concluded that, with respect to these building material emissions—this is from the February 3 document, which I'm not clear that you're aware of yet—private sector research—and they did this for each one of the projects; they told what was being done in the private sector and what wasn't being done and what needed to be done.

> As far as is known, no organization in the private sector is pursuing research to develop sampling techniques in commercial office buildings, nor is any organization in the private sector systmatically studying organic emissions from building materials. Recently both SRI, Inc. and Perk & Elmer have independently developed sampling systems for industrial hygiene applications based upon the use of porous polymer absorbant. Neither system was developed for the longer sampling times needed for the broader range of organic compounds observed at concentrations much lower than typical of industrial hygiene environments.

Therefore, they conclude this is needed and they give a technical approach in great detail as to how they plan to go about this and what they hope to achieve.

You said you canceled these things on the basis you didn't have sufficient information as to what was needed or what the specific approaches would be. I'll read you the specific approach, too, if you'd like.

Mr. TRIBBLE. I don't think that would be necessary.

Mr. OTTINGER. Well, I would just like to know what basis you make these decisions canceling out the work of your own workshops, the work of your own department, the approval of your own staff, and the——

Mr. **Tribble**. I guess I have the responsibility of deciding which recommendations of staff are going forward and which aren't.

Mr. **Ottinger**. And you do this on a political basis or on a hunch basis, or——

Mr. **Tribble**. I do it on the best judgment that I know how, irrespective of your opinion of me.

Mr. **Ottinger**. Without any technical information to indicate that what your own department has told you may be accurate or inaccurate, important or unimportant?

Mr. **Tribble**. I try to get the best advice I can and act accordingly.

Mr. **Ottinger**. Who do you speak to to get that?

Mr. **Tribble**. I'm sorry, I don't have a list of them.

Mr. **Ottinger**. And you don't put it down on paper?

Mr. **Tribble**. I don't go into this amount of detail on all these, no.

Mr. **Scheuer** [presiding]. What kind of people do you speak to?

Mr. **Tribble**. I contact the people such as those that we had at Carmel. As a matter of fact, this entire process was set up for the purpose of bringing together all of the people who are most knowledgeable, both from the laboratories, from the private sector, and anyone who can be considered to be expert in the field. In addition to that, we have routine contact with the trade associations and others who are considered to be knowledgeable in the field.

We have in our budget-generation activities, we do ask the program managers to come forth with all of their proposals, and they do, and almost every year we have proposals which, if all were approved, we would have to be coming to you for appropriations in excess of a billion dollars. We have to go through those and use the best judgment we can, to select those that warrant Federal expenditures. And then we follow through the budget process.

I am simply saying this to say that we cannot afford to adopt all of the recommendations that are made by the researchers and program staff.

Mr. **Ottinger**. In this case, if you funded all these projects that were recommended and approved by your staff, it wouldn't be a billion dollars. It would be in the neighborhood of $900,000, which is authorized and appropriated.

Mr. **Tribble**. In this case we did have $950,000 to work with, and we expect to use it all.

Mr. **Ottinger**. Now, if you go through and cancel all these projects you said you were going to cancel—the letter to you dated June 21, 1983, from Elton J. Cairns, which says:

> However, as you know, there are considerable difficulties involved with abrupt halts of ongoing research activities——

and it skips over and says—

> There are difficulties associated with redirecting and closing out work so late in the fiscal year. According to our DOE approved personnel practices, we must give 90 days notice to staff scientists, which is about the amount of time that remains in the fiscal year, and give severence pay. The combination of these factors means that even if we were to lay off every employee supported by the projects in question, there would be no savings in this fiscal year.

So this can't have been done from the point of view of savings, and if you intend to dismiss all these people, then you're operating flying in the face of the fact that the 1984 appropriation is already in the—for this particular activity in the neighborhood of $1.6 million.

Mr. **Tribble**. I believe I have already stated in this hearing that we worked with the Director of the LBL Laboratory to arrange the work that we were having done there in a fashion that would not require the layoff of any individual, and that the GSO amount at the end of the fiscal year would be adequate to carry the existing group——

Mr. **Ottinger**. Well, if you've cut all these projects, what are all these people going to be doing, playing tiddly-winks?

Mr. **Tribble**. We have worked out and are working out with them some thing that we think are worthwhile.

Mr. **Ottinger**. Which of the projects that are slated for cancellation according to your memorandum here are going to be restored? Is the radon survey going to be restored?

Mr. **Tribble**. Yes. And I must point out that these are not cancellations. These were projects that were never originally authorized, except orally, so that they do not amount to cancellations. They simply are things that we are going forward with that we have decided to use the money that we have available for them.

Mr. **Ottinger**. Isn't that the way the authorization of the work in laboratories is ordinarily done?

Mr. **Tribble**. I'm sorry, I didn't understand that.

Mr. **Ottinger**. The authorization, which you say didn't exist, and was only given in writing—was only given orally—isn't that the way authorization is usually given for particular project work?

Mr. **Tribble**. No, no. We have task assignments that are very clearly written.

Mr. **Ottinger**. What about the passive samplers, is that going to be restored?

Mr. **Tribble**. No.

Mr. **Ottinger**. What about heat exchangers as an indoor quality control technique?

Mr. **Tribble**. We do not plan to do any more work on that.

Mr. **Ottinger**. And what about radon measurements?

Mr. **Tribble**. No; we do not.

Mr. **Ottinger**. And combustion products?

Mr. **Tribble**. We do not.

Mr. **Ottinger**. And building material emissions?

Mr. **Tribble**. We do not.

Mr. **Ottinger**. That's what all these people are doing. That's what this hearing is about. What are all those scientists going to be doing so you don't lay them off?

Mr. **Tribble**. I would be glad to give you a list of the things that have substituted for some of those. I don't have them just off the top of my head.

[The material follows:]

Many of the staff at LBL are involved in bringing to a conclusion those program activities planned for completion in fiscal year 1983. In addition, new initiatives were instituted in the following areas:

Indoor Air Quality Data Base—Initiation of a project to assemble, catalog, store and analyze information from both the public and the private sector on indoor air pollutants. This project will be jointly funded by DOE, EPRI and GRI.

Alternating Pressurization for Air Infiltration Measurement—Acoustical air volume expansion (pressurization) may be quicker, less expensive and more accurate than tracer gas, blower door and infrared devices. Fiscal year 1983 funds will take this approach to proof-of-concept.

Radon Macro-Mapping and Control—Initiation of a project, building on work done by BPA, to correlate radon risks with existing aerial and surface-measured geological, topographical and radiometric surveys, aimed at developing a map of the United States that will indicate those areas that are high, low or medium risk. Control work will be expanded to focus on transferring knowledge of how to minimize or eliminate radon risks in existing and new structures.

In addition to these projects initiated at LBL, we have provided $100 thousand to NBS to initiate an air migration study in multi-chambered large buildings and $500 thousand to ORNL to initiate new heat pipe research with the anticipation of providing an improved understanding of the basic sciences involved with this exchange of air, providing ventilation at lower energy consumption levels.

Mr. **Ottinger**. I see. Is there somebody here who has them off the top of their head?

Mr. **Tribble**. I don't believe so.

Mr. **Ottinger**. Mr. Chairman, I thank you.

I don't think you have demonstrated to us that you've really got backup for these decisions that you made, and since many of these areas really do involve critical matters of health and safety to people who live in these houses, and the scientific community seems to be coalesced on the need for this research and its need to be done by the Federal establishment, and considering LBL's outstanding work in this field, I can't understand at all why this work is being canceled, unless you have some basis for the cancellation.

Thank you, Mr. Chairman.

Mr. **Scheuer**. All right. We thank the witness.

We are going to adjourn for about 10 minutes for this rollcall vote, and then we'll get on with Mr. Ehreth of the EPA.

[Whereupon, the subcommittees were in recess.]

Mr. **Scheuer**. All right. The Subcommittees on Energy Development and Applications and Natural Resources, Agriculture Research and Environment will come to order.

We will hear our witness from the EPA, Donald J. Ehreth, Acting Director, Office of Environmental Engineering and Technology, Office of Research and Development, EPA.

Mr. Ehreth, your statement will be printed at this point in the record in full, so why don't you take 8 or 10 minutes to summarize it, refer to anything you care to which you have heard here this morning, and then I'm sure after that we will have some questions for you.

STATEMENT OF DONALD J. EHRETH, ACTING DIRECTOR, OFFICE OF ENVIRONMENTAL ENGINEERING AND TECHNOLOGY, OFFICE OF RESEARCH AND DEVELOPMENT, EPA, ACCOMPANIED BY RICHARD GUIMOND, DIRECTOR, CRITERIA AND STANDARDS DIVISION; TIMOTHY TITUS, DEPUTY DIRECTOR, ASSESSMENT DIVISION; AND JAMES REPACE, PHYSICIST, AIR POLICY OFFICE

Mr. **Ehreth**. I appreciate that opportunity, Mr. Scheuer.

I would like to also introduce the two gentlemen at the table with me. To my left is Mr. Guimond from the Office of Radiation Programs, and to my right is Mr. Titus from the Office of Toxic Substances, in the event that some questions come up regarding the regulatory side of the program, the regulatory part of the agency's activities.

Mr. **Scheuer**. Between the three of you, are you prepared to testify about the impact on health of cigarette smoking, both to the smoker and the nonsmoker?

Mr. **Ehreth**. Sir, I am certainly not a health expert, so I certainly could not say anything more than the fact that we have some studies—one of our monitoring studies is certainly looking at the particulate emission rate resulting from smoking in controlled areas, but in terms of health effects——

Mr. **Scheuer**. That's an ongoing study.

Mr. **Ehreth**. Sir?

Mr. **Scheuer**. That's an ongoing study?

Mr. **Ehreth**. Yes, sir.

Mr. **Scheuer**. OK.

Mr. **Ehreth**. OK. Thank you, then, sir.

We have been invited to present a statement to clarify the Agency's position on the need for federally funded research on indoor air quality, a review of the research activities carried out by the EPA, and the Agency's plans for future research in the field.

As the committee has been made aware in the past 2 days, completed research on indoor air quality is sponsored by several public and private organizations, including EPA, and it suggests the possibility for public health impacts from indoor air pollution exposures. A considerable body of data has emerged in the past several years that has given us some understanding of the individual airborne pollutants.

Yet, as Dr. Spengler and Dr. Ken Sexton noted in a recent issue of Science, "efforts to assess health risks associated with indoor air pollution are limited by insufficient information about the number of people exposed, the pattern and severity of exposures, and the health consequences of exposures." End of quote.

EPA has the statutory authority to protect public health from air pollution and other airborne contaminants, as required by the Clean Air Act, the Toxic Substances Control Act, the Safe Drinking Water Act, the Federal Insecticide, Fungicide, and Rodenticide Act, and the Uranium Mill Tailings Act.

Federal skills to perform health-based research on the indoor environment are concentrated in three agencies—yes, sir.

Mr. **Scheuer**. Do you plan to read your entire statement?

Mr. **Ehreth**. No, sir. I'm actually just taking parts of it that I want to highlight. There will be several pages we will be deleting. I had had it timed for about 8 to 10 minutes.

Mr. **Scheuer**. Going off the record, I think we would find it more stimulating and more enjoyable if you would just chat with us about the work that you're doing. We have read your testimony. In fact, I read it twice.

Mr. **Ehreth**. All right. Where would——

Mr. **Scheuer**. I mean, you're in charge of your own destiny here, and you can do as you like, but——

Mr. **Ehreth**. I would prefer to highlight a couple of statements that is in the testimony that I think is extremely crucial because I think it reflects a different attitude than perhaps you have heard in the past, and that is EPA believes that continued research on indoor air pollution is important for two reasons:

First, as the Agency begins to deal with the total body burden and health impact of environmental pollutants across media, understanding indoor pollution exposures becomes increasingly important. Second, with a better understanding of the nature of the indoor air pollution problem, the private sector and State and local governments can take more effective action to protect the public if mitigation measures are needed or feasible.

Perhaps we should turn to, as you suggest, to the part of the testimony where we talk about the types of things that we plan to do in the research area. Currently we are preparing a research strategy, a research plan. We have worked with people outside of the Agency to formulate initial drafts of that plan, as well as other Federal agencies. We plan to, and we concur with your recommendation to activate or continue the activities associated with the interagency committee and we would suggest a cochair, that EPA and HHS, CPSC and DOE act as cochairs of that organization. We assume at this moment that EPA would have the lead role in that regard.

Mr. SCHEUER. Yes.

Mr. EHRETH. OK.

Our plans currently include basically four major areas, as we indicated in the testimony: Characterization of sources and emissions, monitoring studies of concentrations and exposures, investigation of the "sick building" syndrome that you were referring to earlier this morning, and the development and evaluation of monitoring methods and equipment.

I would like to just say that in the 1982 and 1983 program, perhaps I could just synopsize that for you. We have characterization of public access buildings, three buildings, a school, an office building, which is a newly constructed office building—and I think just recently completed within a time period of about a year—and a home for the elderly are being studied for levels of volatile organics, benzene and chloroform, pesticides, PCB's, inhalable particulates, and metals.

We will be publishing guidelines for monitoring indoor air quality. This is a report indicating what chemicals to measure and what equipment and methods are currently available. And we have been working with the National Institute of Building Sciences, NIBS, who prepared a comprehensive report on the types of building materials that would normally be found in those three types that we are studying, and consequently, working with that data base, looking for the results as indicated above.

In 1983 the program has been expanded to include eight buildings, including hospitals, which would be studied for the same compounds, with the addition of radon, asbestos, NO_2, CO, and nitrosamines. Half the buildings will again be studied over a 1-year period, and some building materials and furnishings will eventually be placed in a chamber to evaluate and quantify emission rates.

With regard to the engineering program, let me just give you some background on that for a moment, if I may.

In fiscal year 1982 we spent our resources evaluating control devices such as suppressants, means of mitigating asbestos emissions, that type of activity. In 1983 we currently do not have resources for continuing programs in that area.

I think the important thing to note is that the statement, that I did emphasize in the testimony, certainly is indicative that the Agency is serious about a research program in an indoor area.

Now, perhaps it might be more beneficial at this point in time to entertain your questions, sir, and my colleagues and I would be happy to try to address them to the best of our ability.

[The prepared statement of Mr. Ehreth follows:]

STATEMENT OF
DONALD J. EHRETH
ACTING DIRECTOR, OFFICE OF ENVIRONMENTAL ENGINEERING AND TECHNOLOGY
OFFICE OF RESEARCH AND DEVELOPMENT,
U.S. ENVIRONMENTAL PROTECTION AGENCY

BEFORE THE

SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS
AND THE
SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH
AND ENVIRONMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY
U. S. HOUSE OF REPRESENTATIVES

AUGUST 3, 1983

My name is Donald J. Ehreth, Acting Director of the Office of Environmental Engineering and Technology, Office of Research and Development, in the Environmental Protection Agency (EPA).

We have been invited to present a statement to clarify the Agency's position on the need for Federally-funded research on indoor air quality, a review of the research activities carried out by the EPA, and the Agency's plans for future research in the field.

As the Committee is aware, completed research on indoor air quality sponsored by several public and private organizations, including EPA, suggests the possibility for public health impacts from indoor air pollution exposures. A considerable body of data has emerged in the past several years that has given us some understanding of the individual indoor airborne pollutants. Sources, emission rates, concentrations, relationships between indoor and outdoor pollution levels, monitoring methods and instruments, predictive models, body burdens, health effects, exposures, and control methods have been studied, to a greater or lesser degree, for pollutants in a variety of buildings. Yet, as Dr. John Spengler and Dr. Ken Sexton noted in a recent issue of Science (Volume 221, Number 4605), "efforts to assess health risks associated with indoor air pollution are limited by insufficient information about the number of people exposed, the pattern and severity of exposures, and the health consequences of exposures."

EPA has the statutory authority to protect public health from air pollution and other airborne contaminants, as required by the Clean Air Act (CAA); the Toxic Substances Control Act (TSCA); the Safe Drinking Water Act (SDWA); the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); and the Uranium Mill Tailings Act. One example is contaminants which are found in drinking water and which have a clear potential for creating indoor air pollution. These include radon and volatile organic contaminants. Analysis indicates that a major source of exposure to these contaminants may come from inhalation during inside water use, such as in showers. The risk from these contaminants due to inhalation appears to be at least as large as that from ingestion for volatile organic chemicals, and is definitely larger for radon. Under the Safe Drinking Water Act, EPA has authority to conduct research and must issue necessary regulations to mitigate potential health impacts associated with contaminants in drinking water, including those that enter indoor air via the drinking water route.

Federal skills to perform health-based research on the indoor environment are concentrated in three agencies -- EPA, the Department of Health and Human Services (HHS), and the Department of Energy (DOE) (with the active support of the Consumer Product Safety Commission (CPSC) and the National

Bureau of Standards (NBS)). Current authority to act to mitigate indoor air quality problems is spread across a wide variety of Federal, State, and local authorities. Federal agencies with such authorities include CPSC, DOE, HUD, the Department of Labor (OSHA), the General Services Administration (GSA), the Federal Trade Commission (FTC), the Department of Transportation (DOT), Nuclear Regulatory Commission (NRC), the Bonneville Power Administration and the Tennessee Valley Authority, the Department of Defense, and EPA. In this context, it should be noted that many Federal authorities involve the indoor environment while primarily addressing other public concerns. For example, the Department of Housing and Urban Development (HUD) mortgage guarantee programs help provide affordable housing to millions of Americans; by law, mortgage guarantees may not be issued for homes which fail to meet standards for habitability.

State and local authorities affecting indoor air fall into five categories:

- Building codes,
- Energy regulation and tax policies,
- Regulation of energy utilities,
- Health ordinances, and
- Product standards.

In addition, recommendations of voluntary standard-setting professional and industry associations are frequently incorporated in building codes and industry practice. Furthermore, in addition to meeting regulatory requirements, private-sector organizations have a responsibility to consider public health impacts of their products.

Because the institutions with responsibilities for action coincide in part with the agencies and organizations with research responsibility, a coordinated effort is necessary. We concur with the Committee that EPA should continue to work with other agencies by building upon the interagency group that has existed since 1979. EPA would chair such a Federal committee on indoor air quality, with DOE, CPSC, and HHS serving as co-chairs. Additionally, other agencies with an interest will be joining in this effort. Such a committee could promote efficiency in research through the exchange of research plans and results and by facilitating technical assistance efforts to institutions with responsibilities to act to protect public health. This effort should not supplant or subsume existing indoor air quality research programs of other institutions. A major goal should be to work with distinguished scientists to receive expert advice on, and peer review of, Federal research efforts, and to establish a mechanism to encourage public, industry, and interest-group participation in designing future research.

EPA believes that continued research on indoor air pollution is important for two reasons. First, as the Agency begins to deal with the total body burden and health impact of environmental pollutants across media, understanding indoor pollution exposures becomes increasingly important. Second, with a better understanding of the nature of the indoor air pollution problem, the private sector and State and local governments can more effectively take action to protect the public if mitigation measures are needed and feasible.

The purpose of EPA's research program on indoor air quality is to contribute to the understanding of the nature and effects of, and potential solutions to indoor air pollution, if such are determined necessary. To this end, three missions are proposed:

1. To contribute to the characterization of the risks to public health from indoor air pollution and the identification of possible measures, if such are determined necessary, to mitigate or prevent these risks;
2. To develop the data needed to understand the indoor component of total exposure and to establish dose/response relationships for pollutants of interest to the Agency under the Clean Air Act, and to develop the indoor component of data bases to underpin rulemakings under existing EPA authorities; and
3. To apply the results of EPA's unique research expertise in airborne contaminants to assist the actions of other public and private institutions.

A number of major research objectives must be met to define indoor air quality problems, laying sufficient groundwork for actions which might be needed to mitigate associated health risks. We do not believe it to be EPA's responsibility to address each research objective, because some fall more nearly into the missions of other institutions. Further, even on research objectives to which EPA attention will be directed, the active participation of other public and private institutions will be sought, because we consider a cooperative effort between government and the private sector preferable to an approach which excludes those who have an interest or contribution to offer. We are optimistic that joint research is a realistic goal. The four major indoor air objectives for the research community are:

1. Identifying the concentrations of indoor pollutants prevalent in U.S. buildings, their sources, and the parameters affecting source strengths;
2. Describing the relationships among indoor air pollution, building design (including energy consumption), and the thermal comfort of occupants;
3. Assessing the magnitude of the problems of indoor air pollution in terms of exposure, health effects, and risk; and
4. Developing technical solutions to reduce risk and calculating the relative benefits associated with each potential solution.

DOE has been the primary sponsor of research on the second objective and a major supporter of research on the fourth objective. We also feel that private-sector organizations have a critical role to play, especially in the development of technical solutions to reduce indoor exposures, such as those resulting from emissions from man-made sources.

Historically, EPA's research efforts on indoor air quality focused on the first and third major research objectives: that is, on identifying sources and concentrations of pollutants, and on assessing the magnitude of exposures and health effects. Some effort, particularly on radon, has been directed at developing technical solutions to reduce risk.

In the period FY 1975 to 1978, EPA conducted a comprehensive review of existing technical knowledge, the largest study to date characterizing air pollution concentrations in homes and public buildings, and developed a model relating indoor to outdoor air quality. During that period, the Agency began to study asbestos, lead, and radon in indoor air.

In the period FY 1979 to 1981, EPA research activities on the indoor environment expanded. The Interagency Research Group on Indoor Air Quality (co-chaired by EPA and DOE) was founded in 1979, a public/interagency Workshop on Indoor Air Quality Research Needs attended by 250 people was held in Leesburg, Virginia, in December 1980, and an inventory of ongoing indoor-related research was compiled and published in FY 1981. Protocols for field monitoring of indoor air quality were developed in FY 1981, and study of emission reduction strategies for reducing indoor air pollution was begun. During this period (and in FY 1982) studies were conducted of measurement methods for radon decay products in air, the effects of air circulation systems on radon progeny levels, and the health effects of radon daughters in water. An epidemiology study of formaldehyde was performed, and total exposure studies, which include data gathering on indoor exposures, began for carbon monoxide and organic chemicals. Also during this period, the National Research Council was commissioned to appraise for EPA the status of knowledge on indoor air quality and to recommend research needs. Research continued on asbestos indoors, and a regulation on asbestos in schools was promulgated under Section 6 of TSCA. EPA co-sponsored the second international symposium on indoor air, attended by 450 professionals in Amherst, Massachusetts, in October 1981.

In FY 1982 to 1983, total exposure studies with an indoor component continued. Two projects to characterize indoor air quality in large buildings were undertaken, both with an emphasis on organic chemicals, and to measure emission rates from building and maintenance materials. Research to standardize measurement protocols was completed. Research on asbestos and formaldehyde continued. A list of substances present in building materials widely used in the 1970's was compiled in FY 1982. A workshop on radioactivity in drinking water was held in FY 1983 in Easton, Maryland, as a first step in the process to develop standards for radon in drinking water. Dissolved radon gas is released to indoor air from well water used in buildings.

Radon represents a separate problem involving an indoor air contaminant. EPA's involvement with indoor radon measurements began with the identification of unusually high levels of radon in houses in Grand Junction, Colorado, due to the use of uranium mill tailings in house construction. Responding to a legislative mandate, EPA's role includes: designing and conducting monitoring studies, developing measurement methodology and protocols, performing health risk assessments, developing standards and guidance, analyzing the transport and behavior of radon and its decay products in houses, and developing and assessing techniques to prevent and reduce radon levels in structures.

Furthermore, EPA provided assistance to the State of Colorado in measuring radon levels in houses. Since then, EPA has provided assistance to a number of States in monitoring radon levels in houses including extensive studies of radon levels in houses built on reclaimed phosphate land in Florida. More recently assistance has been provided to the State of Montana in surveying a large number of houses in Butte, Montana.

In the past, many have believed that high radon levels in homes were confined to only geographical areas where activities such as uranium milling have caused the problems. However, recently it has become recognized that elevated levels of radon in structures may be more widespread because of high levels of radioactivity in soils in many locations. In addition, construction materials high in radium, very low ventilation in structures, and high levels of radon in well water can also contribute to radon in structures. EPA has just completed an extensive field study of measurement methods for indoor radon for the purpose of establishing standardized measurement protocols. We expect that this study will form the basis for the design of procedures to be used for any additional studies of these types of problems. We conducted these scientific studies because we perceived the need to reduce the cost in collecting this type of data, and improve the quality of the data, so studies by different investigators could be better compared. We also wanted to improve our understanding of radon so that protective measures could be taken where appropriate.

We have assisted States, local jurisdictions, other Federal agencies, such as HUD and the National Park Service, in identifying and correcting problems involving high levels of radon exposure. Part of this effort has been by providing recommendations, standards, and guidelines for exposure to radon decay products for various situations.

In 1971, under its Federal Guidance Authority inherited from the Federal Radiation Council, EPA finalized a new occupational exposure limit for uranium miners to radon daughters. As a result, the exposure limit was reduced to 4 WLM (Working Level Months) from its previous value of 12 WLM.

In 1979, EPA provided recommendations to the State of Florida for radon decay products in houses built on reclaimed phosphate lands. The recommendations were that remedial actions should be taken for all existing residences in which radon decay products exceed 0.02 Working Level (WL). For new residences actions were recommended that would keep the WL within average background levels.

In January 1983, under the Uranium Mill Tailings Radiation Control Act, EPA published a final rule providing standards which determine the levels to which structures contaminated with uranium mill tailings need to be cleaned up. This standard is only applicable to inactive uranium milling areas. It is the only exising Federal standard for indoor radon. The standard requires that structures have indoor radon decay product levels less than 0.02 WL in contaminated areas around inactive mill tailings sites.

To assist States, Federal agencies and the public to correct problems involving exposure to radon, EPA has carried out a number of studies to better understand the entry of radon into houses, the factors which contribute to elevated levels, and what actions can be taken to reduce these levels. For example, the Agency recently completed a study on how to reduce radon entry into houses built on reclaimed Florida phosphate land. In some cases, simple changes to an existing home or minor changes in the design of a new strucutre can make a significant difference in the level of radon in the structure.

In July 1983, we began to prepare a research strategy for EPA indoor air quality research in FY 1984. This document is in internal review, and will require interagency review and peer review by leading scientists before formal adoption by the Agency. We plan to complete this process by about the beginning of the new fiscal year.

Our preliminary thinking is initially to focus research on four major areas, all of which will improve EPA's ability to characterize health risks and define the extent of the problem. In each area co-funding with other institutions is designed to strengthen the quality of research results and to maximize the usefulness of data. These areas are:

1. Characterization of sources and emissions of indoor pollutants, including combustion products, other organic and inorganic chemicals, pesticides, radon, asbestos, etc.;
2. Monitoring studies of concentrations and exposures associated with pollutants, such as unvented combustion gases, radon, and formaldehyde;
3. Investigation of the sick-building syndrome; and
4. Development and evaluation of monitoring methods and equipment.

In addition, we will be exploring the feasibility of conducting studies on health effects associated with exposure to pollutants indoors. EPA does not plan to conduct reseach on airborne pathogens indoors, which is a primary province of HHS, nor on the relationships among building design (including energy consumption), occupant comfort, and indoor air pollution, which is a primary interest of DOE's energy conservation research program. If we have determined that a tractable problem can be defined, we would also explore potential mitigation methods, performance, and cost for eventual use by the public and private sectors. The responsibility of mitigation measures might be shared with other agencies. The planning process for our strategy includes discussions with other agencies and organizations to assure that it will take into consideration their programs and related expertise.

In summary, EPA shares the goals of the Committee that the impact of the indoor environment as a factor in public health be better understood, and that EPA should coordinate its efforts to seek knowledge about indoor pollution with those of other institutions in the public and private sectors. We are intensifying our research efforts on indoor air quality on October 1, in response to the appropriation of $2 million for that purpose.

At this time, I would be pleased to respond to your questions.

Mr. SCHEUER. All right.

You agree that indoor air pollution is a serious problem?

Mr. EHRETH. I certainly would agree that there's a tremendous amount of testimony that suggests that indoor air pollution is a significant contributor to public health problems.

Mr. SCHEUER. Why was it that EPA requested zero funding for indoor air research for 1984? Do you feel you accrued the knowledge base, the total knowledge base necessary to produce action programs in this area, that you've learned all you need to know about the various elements of indoor air pollution and the remedial programs that we ought to get underway?

Mr. EHRETH. I think EPA was more concerned about—and, of course, that is a function of the administration policy. But I think EPA was more concerned about whether or not EPA had the proper statutory authority to regulate once a problem was defined.

Mr. SCHEUER. Well, who is going to define the problem if EPA doesn't have the research funding to do it? Who's going to do it? Nature abhors a vacuum, but in this case I would like you to tell me who's going to fill that vacuum if EPA doesn't fill it.

Mr. EHRETH. I certainly think that we have a role and a problem definition phase, and that is consequently as a result of your actions with the appropriations. We certainly are getting more aggressive in the problem definition part of the research effort.

In the meantime, in other parts of our program, like the drinking water program, we are looking at the radon issue and looking—and in the toxic substances research program we are looking at the problems associated with things like asbestos and formaldehyde and things like that.

Mr. SCHEUER. You know, reading through your testimony—and I had to read it through twice to get the full flavor of the thing—there is a commitment to research. It's pretty enlightened testimony. And it's hard to believe that the same agency that could have produced that testimony is the agency that asked for zero funding in 1984 for indoor air pollution research.

Mr. EHRETH. I certainly can understand your frame of mind at this point in time, sir. And I can only say that there has been a change.

Mr. SCHEUER. There's been a change?

Mr. EHRETH. There certainly has been a change.

Mr. SCHEUER. Is that change associated with Mr. Ruckelshaus' appointment?

Mr. EHRETH. I would say that Mr. Ruckelshaus and Mr. Alm have perhaps perceived the problem in a different perspective than the former Administrator.

Mr. SCHEUER. Well, I am very, very glad to hear that. I am very glad to hear that.

Mr. EHRETH. I think we share that.

Mr. SCHEUER. Pardon?

Mr. EHRETH. I think we share that.

Mr. SCHEUER. Good. That's very encouraging, because there is obviously a lot of talent at EPA.

Mr. EHRETH. Thank you.

Mr. SCHEUER. I hope that your research program will include a real focus on the human health effects of indoor air pollution.

Mr. EHRETH. I have just been talking to the gentleman from the National Academy of Sciences about that, and we have been talking about that specific issue an awful lot, as a matter of fact. Epidemiology studies, as you know—and we have been here before you many, many times—and health effects research is a very, very costly item. We're looking at a total of $2 million. Quite frankly, I think—my opinion is also that the best effort at this point in time is to define the problem adequately, the extent of the problem, to quantify that, and depending on the future of the program, the health effects would certainly be something that would have to be considered.

But in the immediate future we definitely plan to undertake the feasibility of just what our role would be in the health effects. You must realize, of course, that HHS is also involved in this effort, and we would have an interagency activity, CPSC, and there are certain things that they can do much more effectively than we can do.

Mr. SCHEUER. And DOE.

Mr. EHRETH. Yes, sir, and DOE. In fact, there are other agencies as well.

Mr. SCHEUER. Yeah, but somebody has got to be the lead horse.

Mr. EHRETH. Well, I agree with you, sir, and I think I answered that question before. We assume ourselves to be the chair, with the cochairs being these other three agencies.

Mr. SCHEUER. On page 4 of your testimony you stated that local and State governments can more effectively take action to protect the public if mitigation measures are needed and feasible. Well, maybe they are and maybe they aren't. Their record in that connection is not awe inspiring.

But certainly, don't they need the research, don't they need EPA to do the research to identify where mitigation measures are needed and how the State and local governments can and should take action? Isn't that your clear role?

Mr. EHRETH. Sir, I believe that's the theme that I would like to convey in that, is that the research would be done primarily by this collective interagency body, and with the cooperation of the private sector, so that we can pass that information and that state of knowledge to these people who are closer to the problem.

Mr. SCHEUER. What specifically are you going to rely——

Mr. EHRETH. Sir?

Mr. SCHEUER. What specifically are you going to rely on the State and local governments and the private sector to do?

Mr. EHRETH. Well——

Mr. SCHEUER. You said, on the bottom of page 4, "* * * with a better understanding of the nature of the indoor air pollution problem, the private sector and State and local governments can more effectively take action to protect the public if mitigation measures are needed and feasible."

Mr. EHRETH. Going back to page 3 of the testimony, I have listed five categories: Building codes, energy regulation and tax policies, regulation of energy utilities, health ordinances, and product standards. Now, some of those can be done by the State and some of those can be done by the private sector themselves as well, self-regulation. Some of this has been effective in some areas.

Mr. **Scheuer**. What areas would you say the private sector has distinguished itself in in self-regulation?

Mr. **Ehreth**. In self-regulation? Well, as a whole, or related to indoor air are you talking about?

Mr. **Scheuer**. Well, let's talk about indoor air pollution.

Mr. **Ehreth**. Well, it is my understanding that the ASHRAE organization has been relatively effective with controlling ventilation and setting standards on ventilation exchange rates and that sort of thing. I do know that EPRI is involved as well in looking at—in conducting research in this particular area.

There are other—in other parts of the overall environmental program there have been successes—and not so much successes, quite frankly, sir. I don't have any specifics here, but perhaps if I could give that some thought maybe we could give you some specifics.

Mr. **Scheuer**. Very good. I would ask unanimous consent to hold the record open for another 10 or 12 days and I would request the gentleman—I would request, Mr. Ehreth, that you submit that information in writing. That would be extremely helpful.

[The material follows:]

The outstanding example of private sector action involving indoor air quality of which I am aware is ASHRAE's (American Society of Heating, Refrigerating and Air Conditioning Engineers) "Ventilation for Acceptable Indoor Air Quality Standard" (62-1981). This standard forms the basis for the regulation via State and local building codes of ventilation rates in large and small, public and private buildings affecting more than half of the U.S. population. Ventilation rates, measured in cubic feet per minute per person, are prescribed for different kinds of rooms based on activities found therein (bathrooms, bedrooms, conference rooms, etc.). Areas in which smoking is permitted are required to have five times the air flow in rooms in which smoking is not permitted.

Several States have taken action on indoor air quality. California has established the first general State research program on IAQ. Maine has investigated the problem of radon in drinking water. Florida, based in large part on guidance from EPA, has established requirements concerning radon in homes built near phosphate lands. Massachusetts has banned urea formaldehyde foam insulation, which has been linked to homeowner complaints of indoor air pollution.

In the private sector, the Electric Power Research Institute and the Gas Research Institute have been active in conducting indoor air quality research; together, they are sponsoring several million dollars of research per year. Each has a direct interest in the problems of indoor air quality: electric utilities have large weatherization and insulation programs aimed at freeing electricity from existing users for new customers (which could be jeopardized by indoor air pollution) and gas utilities have made a commitment to find out the extent of indoor air quality problems caused by emissions from unvented indoor combustion of natural gas.

The actions I've listed are relatively few in number. But we've seen a clear trend towards greater interest and action in State and local government and the private sector. I hope that this trend will increasingly result in actions taken in enlightened self-interest by public and private institutions to protect public health.

Mr. **Scheuer**. On page 4 you do say that EPA would chair a Federal Committee on Indoor Air Quality——

Mr. **Ehreth**. Right.

Mr. **Scheuer** [continuing]. An interagency group, with DOE, CPSC, and HHS serving as cochairs. And I presume that at the bottom of page 4, when you are talking about the private sector and the State and local governments taking effective action to protect the public if mitigation measures are needed, that that subsumes that the Federal Government would do the research necessary to give them the knowledge.

Mr. **Ehreth**. Yes, sir. I think that's the same question you just asked me a moment ago, just before.

Mr. **Scheuer**. Yeah, right.

You do have a very painfully small research budget for next year of $2 million, that was thrust upon you, and presumably the present leadership of the Agency is it feels a little more comfortable with that than the prior—than the leadership that they succeeded.

What intentions would you think the EPA would have of pursuing research funding beyond fiscal 1984 and making this a continuous, systematic, well-organized, long-term research effort?

Mr. **Ehreth**. That question can be answered by saying that we are—as our testimony states on page 4—that we are serious about continued research in the indoor area. However, there are caveats, as you and I both know, that there is a budgetary process that takes a pathway between you—between us and you—that has to be followed, and decisions will be made along those lines as to just what extent continued research here will be actually seen in the future—you know, to what extent it will be, what the magnitude will be. That's a budgetary issue, sir.

Mr. **Scheuer**. Well, I understand that. Of course, all these things are budgetary issues. But looking at it from the risk-benefit point of view, we spend 90 percent of our time indoors, right?

Mr. **Ehreth**. Yes, sir, 89 percent, different people.

Mr. **Scheuer**. Eighty-nine percent, OK. And we are able to control that indoor environment a great deal more easily and more cost effectively than we can control our outdoor environment.

Now, we are talking now—and there are all kinds of Federal minds at work—devising strategies for improving the outdoor environment, improving acid rain control, and improving the carbon dioxide problem, the sulfer oxides in the air. We're worrying about 17 polluting plants in the Midwest and what happens in this extremely complicated business of transport and where it falls, how long it takes, where it lands, on the east coast and in Canada, and we're talking about a possible need of spending many, many, many billions of dollars to control our outdoor environment, where we spend 10 percent of our time, 11 percent of our time.

Wouldn't it behoove us to—and we're spending several hundred million dollars on research on the outdoor environment. Wouldn't it behoove us to spend an appropriate amount of—to direct an appropriate quantum of resources, human resources and dollars, at the area that seems most manageable? It is where we spend most of our time, so the benefits would be enormous, and where the spaces are small, and where we can control what goes into those spaces and what comes out.

It seems to me that, from the cost benefit point of view, it would be sheer madness to ignore indoor air pollution and spend all our time and money and efforts on outdoor air pollution.

Mr. EHRETH. I think that question has many parts to it. Let me begin by saying that I certainly believe that, in consideration of exposure and overall health risk, the indoor air part of that equation is very critical and very crucial to understanding the full health effects issue.

People do move in and out of houses, however. Housewives tend to stay in the house quite often, whereas the husband will go—or whoever the worker is in this case—will tend to—and I certainly don't want to be chauvinistic here—sorry about that—but whoever it is that leaves the house and goes to work does change different buildings and different climates and different environments. So that overall equation is very crucial to understanding that.

Now, where do you regulate and how do you regulate is an issue that I certainly am not qualified to address. I don't know if it's more cost effective to regulate inside——

Mr. SCHEUER. Well, we're not getting to the point of regulation.

Mr. EHRETH. You said control. I guess I assumed regulation by that. OK.

Mr. SCHEUER. We're talking now about research, accruing the knowledge.

Mr. EHRETH. OK.

Mr. SCHEUER. What I'm saying, first of all, when you develop the knowledge about outdoor air pollution, you have an enormously expensive job of somehow or other battening down the hatches with the smokestack industries. You're talking about billions, tens of billions, maybe ultimately hundreds of billions of dollars, with scrubbers and washers and whatnot. With indoor air pollution, a lot of it is not going to be a cost to Government at all. You are giving people the wherewithal to control their own health outputs. They'll do things by themselves in their own homes. That's a lot of it. And workers will demand that companies take comparatively inexpensive, I suppose, remedial steps at the factory and the department store and the workplace in general.

But a lot of it is very much more easily self-executing, without a great, big regulatory process, it seems to me, than the business of outdoor pollution. It seems to me that would almost—I wouldn't want to let outdoor pollution sit on the back burner——

Mr. EHRETH. No; I can——

Mr. SCHEUER [continuing]. But it might be logical to say, "well, first things first. This should be our first target of attack, indoor air pollution." It's where we spend 90 percent of our time, it's cheaper, it's within our control, it won't require a lot of Government regulation; intrinsically a lot of it is not subject to Government regulation; we're not going to go into people's homes; maybe municipalities will regulate builders and regulate the radon and so forth and the water supply and various construction materials. But it is intrinsically a very much more manageable problem. It is far easier for us in society to cope with it.

Therefore, all that we need to trigger, all of us as citizens and as consumers of homes—and as articulate workers in the workplace, we're concerned about our own health—all we need is a certain knowledge base, and then a hell of a lot of things are going to flow automatically from that.

It seems to me that, from the point of view of cost benefit, we get a terrific bang for a buck for every dollar spent in research in indoor air pollution as compared to outdoor air pollution.

I have been fighting the good fight to know more in outdoor pollution. I have been very frustrated at this catch 22 that Congress has been in, where the EPA research budget on pollution and other matters has been cut 50 percent or more, and then when we come to regulate, EPA tells us we don't know enough. Well, we probably don't know enough. We should have done the research.

So I am not for—I don't want my remarks to be construed as favoring reducing research on outdoor pollution, far from it.

Mr. **Ehreth**. I understand.

Mr. **Scheuer**. But it seems to me that there certainly ought to be a crash program to improve the knowledge base that we need on indoor air pollution, because once we accrue that and turn loose our citizenry, as homeowners, as workers, they're going to bang the table and a lot of things are going to happen without any further intervention of Government, without a costly Government apparatus, without costly Government subsidy programs.

Mr. **Ehreth**. Sir, I certainly follow your intuitive process that you're conveying to me there. It may well prove to be more cost effective to society to reduce indoor air pollution, and I would certainly hope that that's the kind of research program we would design and collectively engage in with the other agencies and the public and private sectors to get at those kinds of answers. That's our intent.

As I said before, and a third part of that previous question that you asked me, is that I feel very confident that my leadership is serious. This testimony would not have cleared had that not been the fact. My leadership is very serious about an indoor air research program, and if there is one message I can convey to you today, I want to make sure that that is clearly understood.

Mr. **Scheuer**. Well, we receive it, we accept it with great anticipation of great things to come. It is manna from Heaven after the drought that we have been through over at EPA. We don't have to—we don't have to burden ourselves or the record with any discussions of recent past history at EPA——

Mr. **Ehreth**. Thank you, sir. [Laughter.]

I wouldn't know how to answer that question, anyway.

Mr. **Scheuer**. That leadership is very, very much appreciated over here on Capitol Hill, you can be sure of it.

Mr. **Ehreth**. I will be sure to certainly convey that message back to Mr. Alm and Mr. Ruckelshaus.

Mr. **Scheuer**. I hope you will.

I have a lot of specific questions, but they are all subsumed in your good faith intention to produce an integrated, comprehensive research strategy for indoor air pollution, and coordinated with the other agencies, in which EPA is going to be the lead horse.

Mr. **Ehreth**. That's what we're saying, sir.

Mr. **Scheuer**. That's what you're saying. So I don't know the point—I just don't know, since the Sun has passed over the yardarm long since, why we have to go into a lot of the details.

You presented in the past few years a lot of interesting projects in indoor air pollution R&D. There is obviously a lot of talent there that's been zeroed in on these matters, and in sort of a collective ad hoc fasion, but without an overall grand design and without any seeming effort to do the whole job. It seems to me that's changed. So——

Mr. **Ehreth**. It certainly has.

Mr. **Scheuer**. Well, I don't want to appear a Pollyanna or a Dr. Pangloss. Maybe this is the time for us to sit back and with a certain amount of hope and faith and wait and see.

Mr. **Ehreth**. We would hope we could continue to work with you in this sort of climate and atmosphere.

Mr. **Scheuer**. Well, we certainly hope so. I have enormous confidence and very high respect for your leadership. I think it is one of the great things that has happened in America in recent months.

One thing that we would like to do after the Labor Day recess is to ask you to come back here with your smoking, your tobacco health experts in hand. We thought we were going to have—we thought you were going to be accompanied by——

Mr. **Ehreth**. I'm sorry. I wasn't aware——

Mr. **Scheuer**. That's all right. We'll be happy to talk to them after Labor Day.

Mr. **Ehreth**. I will find some smoking health people in our shop.

Mr. **Scheuer**. There are some of us who are very much concerned about smoking. I, myself——

Mr. **Ehreth**. Right off the top of my head, I'm not too sure that we really have any research ongoing in that particular area, so I would have to do some searching to make sure we do or don't, quite frankly.

Mr. **Scheuer**. Do you have a chap down there by the name of James—let's go off the record for a minute.

[Discussion off the record.]

Mr. **Scheuer**. Sit down. We are happy to know that you're here, Mr. Repace.

Can you tell us what work EPA is—back on the record. And the gentleman's name is James Repace?

Mr. **Repace**. That's correct.

Mr. **Scheuer**. And can you give us your title?

Mr. **Repace**. Yes. I am James Repace. I am a physicist in the Air Policy Office.

Mr. **Scheuer**. Good. Can you tell us about the work that EPA has done and that it might contemplate doing in the whole area of the impact of smoking on human health, in the workplace, in the home, in the Eastern Airline shuttle? [Laughter.]

Mr. **Repace**. Well, that's a tall order. First of all, my own research, I have been looking at the exposure of the population to the particulate phase of ambient tobacco smoke, and I have recently come back from the Fifth World Congress on Smoking and Health in Winnepeg where I gave a paper on modeling exposure of nonsmokers to ambient tobacco smoke, in which I presented a theoretical methodology to determine the exposure of the average nonsmoking individual in the United States to ambient tobacco smoke.

I believe that it is of the order of about 1.4 milligrams of tobacco tar a day, which is of the order of about three low-tar Carlton cigarettes. So the average nonsmoker is a passive smoker or an involuntary smoker.

We feel that this exposure has an impact on the way the Environmental Protection Agency sets its particulate standard, because it would appear that the bulk of the exposure of the population to airborne respirable particles may be coming from indoor air pollution and, therefore, it has a bearing on the dose response function that we use for determination of the effects of particulates, airborne particulates, on human health.

Exactly how it interplays, we haven't uncovered yet. The research office is attempting some studies now in offices and in schools, and in one old person's home, monitoring of particulates, but obviously there is a need for a large-scale program in terms of sampling statistically—let's say Washington, D.C., just as an example—to take a snapshot, in essence, on the basis of personal monitoring of what people's exposures are in different microenvironments that they proceed through during the day and to determine what fraction of probability weighted exposures occur from indoor microenvironments. Then we can better set our outdoor air standards and also be in a position to give advice on what precautionary measures might be taken for indoor exposures to respirable particles.

Dr. Hirayama from Japan also presented a new paper at the Fifth World Congress in which he indicated there is now evidence of ischemic heart disease from passive smoking as well as lung cancer and respiratory disease. So to answer your question——

Mr. SCHEUER. To the nonsmoker?

Mr. REPACE. To the nonsmoker, that is correct. He has uncovered dose response functions and the elevation in risk appears to be generally of the order of a factor of 2.

Dr. Richard Peto from Oxford indicated he believes that the annual mortality from passive smoking in the United States ranges from several hundred to several thousand deaths per year. I would not differ with that range of estimation. I think it's probably at the higher end rather than the lower, and I would simply observe that the hazardous air pollutants that EPA regulates, before control, range from 1 death per year to probably 150. So that certainly would represent a very large impact in terms of our regulatory program.

Mr. SCHEUER. I should say.

How many people do you have working on the health impacts of smoking in the environment?

Mr. REPACE. As far as I know, I'm the only one.

Mr. SCHEUER. You're the only one?

Mr. REPACE. Yes, as far as health impacts. The Office of Research and Development does have a monitoring program designed to measure the impact of respirable particles in indoor environments.

Mr. EHRETH. Excuse me, sir. That was that study I was referring to earlier, of the three buildings.

Mr. **Scheuer**. Well, you can express our pleasure and our hope and confidence to Mr. Ruckelshaus.

Mr. **Repace**. Thank you, sir.

Mr. **Scheuer**. And also our concern that you are so poorly supported and there seems to be such a dearth of manpower directed at this problem. Our confidence extends to our sense that he will remediate this problem among many others and apply more talent and more resources to this very important health problem from which 300,000 people are dying every year in the United States.

Would you be willing for us to print your paper as part of the record of this hearing?

Mr. **Repace**. Certainly. I would be happy to transmit a copy of that to you, as well as my other publications.

Mr. **Scheuer**. Very good. And if you can get over a paper of the Japanese gentleman that you mentioned——

Mr. **Repace**. I did bring back a copy of that with me. I don't have it here. I have it——

Mr. **Scheuer**. All right. We're holding the record open for about 10 or 12 days anyway for some information that Mr. Ehreth is going to provide us, so that will give you time to get that over here. We'll be happy to include that as part of the record.

Mr. **Repace**. Thank you.

Mr. **Scheuer**. OK. You have all been very, very patient. It's almost quarter till 1 and you've sat here a number of hours. Your testimony has been very interesting, very forthcoming, and we sit here full of hope, and please pass our confidence and our hope on to your boss, and we look forward to seeing you after Labor Day.

Mr. **Ehreth**. Thank you very much, sir.

Mr. **Scheuer**. Thank you.

The hearing is adjourned.

[Whereupon, at 12:42 p.m., the subcommittees were adjourned.]

APPENDIX

Additional Material Submitted for the Record

A STATEMENT OF THE
NATIONAL INSTITUTE OF BUILDING SCIENCES
ON INDOOR AIR QUALITY RESEARCH:
CURRENT STATUS AND FUTURE NEEDS

In recent years there has been a significant increase in the attention given to the indoor air quality issue by the news media and by trade publications. Some sectors of industry have been criticized for creating, knowingly or otherwise, health hazards by exposing housing and building occupants to out-gassing from building materials, soil treatment chemicals, and the like. Many view these criticisms as lacking in appreciation for the complexity of the issue.

The complaints about indoor air quality are not unique to the United States or to the U.S. construction industry. In 1979, the Danish Building Research Institute identified several efforts, sponsored by medical and research institutions, to establish thresholds for formaldehyde off-gassing from particleboard and plywood. The Austrian and Swedish governments established research programs on formaldehyde and radon gas, as two of the more significant indoor air pollutants, as early as 1976. The Canadian nuclear regulatory agency conducted exploratory work on indoor radon measurement in 1975 as part of a nation-wide review of hazardous waste disposal practices. Others explored the effects of radon as early as the 1950's.

According to the U.S. General Accounting Office, most foreign researchers and government officials agree that product quality control is the most effective and readily implemented corrective measure. In 1980, the GAO pointed out the need for adequate material standards and appropriate test methods. Enforcement of the standards would be achieved through testing at time of production to control those products which have been identified as sources of indoor air pollutants.

There have been several recent efforts by the U.S. building community to set new standards to keep pace with the indoor air quality issue. ASHRAE, the American Society of Heating, Refrigeration and Air Conditioning Engineers, has updated its Standard 62, Ventilation for Acceptable Indoor Air Quality. Recent attempts to adopt portions of the 1981 edition of this standard by two of the three major model building code organizations have been defeated because the majority of voting members considered them unenforceable due to lack of available or affordable equipment and expertise, and lack of ability to control the exterior environment (i.e., the level of pollutants in the outdoor air). ASHRAE is currently working to again update Standard 62.

The indoor air quality issue has bearing on human well being in nearly all building occupancy types. However, due to the great amount of time spent in the home, residential occupancies usually receive the greatest attention. Rising energy costs over the past few years have mandated changes in residential construction standards in order to improve thermal efficiency. In houses, increased insulation and other features to improve the efficiency of the building's thermal envelope have been added, as have more thermally efficient exterior windows and doors, to the point where the introduction of fresh outside air has become the major source of heat loss. Residential construction standards as late at the 1970's allowed outside air infiltration of at least one change per hour. Many residential forced-air heating systems were equipped with ducted outside air intakes that kept homes under a positive static pressure with preheated air as a technique for controlling drafts. This deliberate introduction of outside fresh air has been virtually discontinued as standard practice, except where required by code. Construction standards which minimize air infiltration, together with the use of modern building components such as non-outside exhausting (ductless) kitchen and bathroom ventilation fans, have now been adopted to the extent that many new homes are just short of being "hermetically sealed". In homes such as those occupied by the elderly, where little traffic through exterior doors takes place, outside fresh air introduction has been reduced in some cases to less than 0.1 air changes per hour.

In the past, under less stringent air infiltration standards, indoor air contaminants such as nitrous oxide, carbon monoxide, chlordane, radon, ammonia and formaldehyde seldom had the opportunity to accumulate to the extent that occupants even noticed their presence, let alone experienced discomfort or other health effects. With today's tightly constructed homes, the public's concern over indoor air pollution has been aroused to the point that hundreds of lawsuits have been brought against home manufacturers, material producers, and more recently home builders, charging negligence and breach of warranty. Damage awards to successful plaintiffs are commonly quite large.

The nation's building and scientific communities have chosen a defense based upon the identification and measurement of individual contaminants and their comparison against attempts to determine safe tolerable levels. There is a lack of definitive and accepted data with which to establish widely accepted health effects for most of the suspected indoor air pollutants. Each day the confusion increases as new contaminants are discovered, prior test procedures are refuted, new measurement techniques adopted, court rulings overturned, formerly accepted data rejected, and so on. It would appear that it will take some time, perhaps many years, for the scientific community to arrive at a set of universally acceptable data and thus recognized thresholds of contaminants. Until this is accomplished, there remains a public demand for some other procedure to protect their interests. The building industry is also in need of reasonable protection from the harrassment and financial drain of litigation. At the same time, occupants must be protected from discomfort or injury due to air contaminants.

In addition to suspected and known pollutants entering the home from materials and appliances, occupants themselves unknowingly introduce additional potential contaminants when they bring such things as furniture, clothing, carpet, drapes, cleaning fluids, and paneling into their homes, or engage in such routine activities as cooking and smoking. Is the home building industry negligent in their failure to provide homes that maintain indoor air quality that is uncontaminated by pollutants regardless of where, how, or by whom introduced? Over the years procedures have been developed and accepted to protect people from other potential hazards--for instance electrical systems in homes are equipped with automatic circuit breakers that protect the home and the occupant from danger even in most cases of misuse or abuse.

In addition to trying to identify, quantify, and establish threshold limits for every known or suspected contaminant (and those not yet identified), reconsideration should be given to such concepts as the introduction of fresh outside air to the extent of one full air change per hour. The technology and equipment now exist to accomplish this at little penalty in energy efficiency through the use of heat exchangers which utilize the temperature of the air being exhausted to precondition the incoming air. Wide-spread adoption of this practice would do much to reduce the cost of such equipment and encourage HVAC equipment manufacturers to incorporate this capability into their primary equipment, thereby reducing costs even further.

If such a solution to the indoor air quality problem is of merit, how and by whom might it be furthered within a reasonable time frame? One home builder estimates such a system would add approximately $500 to the cost of a new 1400 sq ft home. With mass production of mechanical equipment which incorporates these features, this cost could come down to less than $50 per unit. The estimated energy use costs to operate the system are expected to average between $50 and $100 per year.

Benefit/cost and risk analysis is a good tool for evaluating potential solutions, but its use is only as valuable as the accuracy of the data used in its application. The lack of these authorative data is one of the frustrating aspects of the indoor air quality issue. Many want public authorities to take action promptly but some of the "prompt" legislative and regulatory actions taken to date have been challenged successfully due to the absence of a substantive data base. Regulatory solutions are usually more costly and less effective than are private initiatives to solve these kinds of problems.

The scientific community has been in the vanguard of the movement to study this issue. More recently other affected interests such as the design professions, product manufacturers, contractors, home builders and building owners have taken an active part in such studies. This is viewed as forward thinking. As these interests begin to question, translate, accept and utilize the scientific findings, solutions in the form of new products, methods and standards will emerge based on new and accepted technology.

In order for this to come about, it is necessary to provide for the early involvement of the affected interests in planning, conducting and evaluating the overall research agenda currently proposed at the Federal level.

The National Institute Of Building Sciences (NIBS) would like to point out the lack of an established and authorative data base on the significance of the indoor air quality problem in the United States. Many government agencies, research organizations and academic institutions are exploring aspects of the problem. The Environmental Protection Agency, the Department of Energy, Lawrence Berkeley Laboratory and Princeton University are but a few of the many endowed centers of research on various aspects of indoor air contamination. Unfortunately for the building industry and the concerned public, very little reliable information is being compiled in a useful format and maintained in a central location for general consumption. However, the more attention the media draws to the subject of indoor air quality, the greater the demand will be for authoritative documentation of scientific data.

There is a wealth of research data and talent in the building community. The Congress and the Administration should tap this valuable resource. The guidance given in Senate Report No. 98-152 (page 49) and House of Representatives Report No. 98-212 (section 9) is a good start in the right direction, but these suggestions must be pursued to fulfillment. The National Institute of Building Sciences (NIBS) was established by the Congress to be a catalyst and a forum for just this purpose. With proper support, the Institute is willing and able to bring the diverse building community interests together to make authorative findings and stimulate their use in the public interest.

NATIONAL INDOOR ENVIRONMENTAL INSTITUTE
A nonprofit agency

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August 15, 1983

Dr. Eugene Frankel
Staff Member
House Committee on Science and Technology
B374 Rayburn Office Building
Washington, D.C. 20515

Dear Dr. Frankel:

The National Indoor Environmental Institute is a nonprofit technical agency founded last year by former staff members of the Buildings Research Program at the Center for Energy and Environmental Studies, Princeton University, who joined ECRI, a major nonprofit biomedical engineering organization. Our goal is to aid the American people by conducting practical applied research and providing information, consultation, and diagnostic services in the field of indoor air pollution. Our organization is totally independent and beholden to no commercial interest. We accept no support from manufacturers or installers of air pollution mitigation equipment.

We believe that indoor air pollution is an important public health concern. The average American citizen spends more than 80% of his time indoors, and almost all significant air pollutants are more concentrated in indoor environments than outdoors. Through the Clean Air Act, the Federal government has been responsive to the legitimate concerns of the American people about the quality of outdoor air. There has not been a corresponding commitment to even learn about indoor air pollution.

Indoor air pollution problems are found in all classes of buildings. The American Council of Governmental Industrial Hygienists (ACGIH), Occupational Safety and Health Administration (OSHA), and National Institute of Occupational Safety and Health (NIOSH) have all been active in controlling the hazards of the manufacturing workplace. There has been much less work in office spaces, areas in which "tight building syndrome" and other afflictions have become epidemic, affecting both productivity and health. To date, investigative methods are still crude and few organizations have been able to claim success in pinpointing and eliminating problems in these buildings. An active and sustained program to determine what is used in buildings, what is found in their air, and how to fix problems once discovered should be a high national priority.

In this testimony, however, we want to focus on the indoor air quality problems in American housing. For several important pollutants, there have been very limited distributional or "base-line" studies.

Some work has been done by the Lawrence Berkeley Laboratory on energy-efficient buildings, by workers at Yale on kerosene heater pollutant levels, and by several utilities in their own regions. Still, we estimate that the total of air pollution measurements in houses in the U.S. has encompassed fewer than 10,000 houses - and most of this represents a single Air Force study of chlordane in base housing! In 1983, we simply do not know how much pollution is present in our national housing stock and how it differs in various parts of the country, and by type of house. We do not know how much this pollution affects health now, or is likely to increase the risk of cancer later in life. Only a vigorous and highly-directed research program can correct this situation, and we urgently request that the House Committee on Science and Technology give high priority to this issue.

Let us consider some specific pollutants before making specific recommendations:

FORMALDEHYDE will present extraordinarily complex public policy problems, problems which will require a great deal of additional research and information. To begin with, formaldehyde is ubiquitous, with billions of pounds used annually, primarily as a feedstock for the production of ureaformaldehyde resins and other products. Measurable amounts of formaldehyde are emitted by many common products, from permanent press garments to interior plywood and UFFI (ureaformaldehyde foam insulation).

Formaldehyde also presents health risks. It is a known animal carcinogen, and thus suspected of causing cancer in humans, as well. These risks were dealt with in the EPA PRL-1 "Assessment of Formaldehyde" draft, for which a final version does not seem to have been released. It appears that some people, perhaps a few percent of the population, may develop extreme "allergic" reactions after exposure to formaldehyde.

In the face of mounting controversy, last year the CPSC moved to ban the use of UFFI for residential wall insulation, because of complaints about formaldehyde exposure following poor installations. Although this ban has been overturned by the Fifth Circuit Court, there are many lessons from it: (A) We do not believe that there is yet enough information on the distribution of formaldehyde in houses to infer that UFFI houses, as a class, have significantly more formaldehyde than other important classes of housing.

(B) There have been very few field studies of the actual emission of formaldehyde from UFFI-insulated walls. (C) There has been little effort to determine, from a realistic sample, what fraction of UFFI houses actually have high formaldehyde concentrations. (D) There has been little effort to open and examine wall cavities in a representative sample of houses to determine the physical condition of the material some years after installation. (E) There has been little research on what to do about cases of excess formaldehyde emitted by UFFI insulation. Our own experience suggests that removal, an expensive last resort, may not always be effective and is generally unnecessary.

RADON is an inert, radioactive gas formed naturally as a component of the uranium decay series. Excess exposure to the immediate airborne progeny of radon has long been implicated as a major cause of excess lung cancer in miners. Our data, and that of others strongly, suggests the following important conclusions: (A) There is not nearly enough data from this country. Indeed, the NCRP (National Committee on Radiation Protection) had to rely on Canadian data to develop risk estimates. (B) In general, the concentration of radon in houses is controlled by location. In some regions of the country, which include much of Maine, parts of central New Jersey, much of eastern Pennsylvania, possibly most of the Appalachian limestone rock belt, and parts of Colorado, the rocks yield enough radon that excess amounts enter the houses through their foundations. (C) Within these areas, newer houses may have a lot of excess radon, but almost no older ones will. This is because the newer houses are built more "tightly" to conserve energy by minimizing ventilation. This traps radon (and other pollutants) and may create serious health problems.

Our extensive experience in eliminating the causes of excess radon in houses has convinced us that no house need have excess radon. For new housing, control is feasible through minor modifications of construction methods. For existing houses, cost-effective solutions are almost always available.

The problem is simple: we need large-scale surveys to find where radon is a problem. We need information for architects, contractors, and the building trades so that they can build safely. We need to train public health authorities to find and help fix these problems. Half the States do not even have the ability to measure radon in air!

CHLORINATED PESTICIDES: Termiticides such as chlordane have been applied to many millions of houses in the U.S. over many decades. In some cases, occupants may have been sensitized to components of these formulations. At the present time, despite evidence that some compounds have been used inappropriately and that earlier formulations may have been contaminated with potent unwanted by-products, there has been little study of the actual airborne concentration of pesticides in American houses and apartments. Only the Air Force has carried out a systematic study. At this time, we cannot even say whether the problem is likely to be more or less worrisome than the recent lead-based paint issue.

COMBUSTION GASES are an increasing problem because of the growing popularity of unvented kerosene heaters and the large-scale return to heating with coal or wood. It is clear that the actual pollutant levels, whether of exotic organics or of carbon monoxide and oxides of nitrogen, will be highly variable, depending on details of equipment, utilization, and leakiness of the structure. Yale has carried out a pilot study of pollutant levels in 350 houses, but much more effort is required to characterize the distribution of pollutants.

At the same time, it is imperative that the distribution of ventilation rates (air exchanges between interior and outside of houses) be measured as well, because the role of ventilation is vital. With this information, we will be able to predict the effects of other pollutants as they become of concern.

This brief list skims the surface of some of the more urgent problems at this time. We urge consideration of the following policy recommendations as a basis for Congressional direction to the Department of Energy, Environmental Protection Agency, and other relevant organizations:

1. Indoor air pollution should be recognized as a major public health concern for our society. Children being exposed to radon or other carcinogens today will have excess risk of developing cancer during their productive years.

2. Large-scale distribution studies are required to determine which locales and which components of the housing stock are affected by specific problems. In addition to their present health value, such studies will provide an important "base-line" for evaluating changes in the housing stock as newer designs are introduced. The distribution studies are also critical for retrospective epidemiological studies of acute irritants and form the basis for prospective epidemiology for carcinogens such as radon.

3. This nation should begin, as soon as possible, to emulate other developed countries, e.g., Sweden, Canada, United Kingdom, and undertake the study of air pollution problems in housing and offices. For costs to be manageable, such a program will have to rely on air pollution monitors which can be deployed by laymen in their own homes and offices, and the program will have to be carefully designed to meet legitimate concerns about government invasion of people's homes. It may be appropriate for such programs to be carried out by utilities or other capable third parties. We have been engaged in such a study over this past year, but in a very limited manner.

4. For some pollutants, such as radon, formaldehyde, and nitrogen dioxide, field-tested "passive" monitors which can be deployed by laymen are available. Passive monitors for other pollutants are not yet available for environmental applications, but are needed. A "Request for Proposals" for the development and validation of monitors for chlorinated pesticides, respirable particulates, and trace organics should be executed. Brookhaven National Laboratory has developed a passive monitor for ventilation rates ("leakiness"), but additional validation is required before it can be made available for large-scale use. We believe that it is at least as important to gain some information about 100,000 houses as to carry out another intensive study of 10 houses. Such studies have been valuable and should be continued, but it is now time for large-scale surveys.

5. Because the building industry is so fragmented and has such little research capability, and because the problems are regional and national rather than local, research on building-related components of the problem should be carried out with Federal funding. The benefits

of such research are national and impossible for any single group to "capture." Such research would deal with many of the questions outlined above in discussions of formaldehyde and radon. Clearly, a strong research program would address many other questions as well. We would predict that such a program, implemented at the level of 15 to 20 million dollars annually, would be highly cost-effective in terms of illness avoided. It would be likely to be cost-effective in energy savings as well, by developing better methods to accomplish conservation goals as well as health protection.

6. Finally, we need new mechanisms to assign responsibility and recover the costs of remedial action in cases of indoor air pollution. At present, the homeowner has little recourse beyond the doctrine of strict contractor liability if a problem develops. In the case of problems which the builder could not have been expected to foresee, this does not seem to be fair. It certainly is inefficient and will discourage any innovation in this fragmented industry. We do not know whether the answer is in government-backed insurance (like flood protection schemes) or by regulation of the insurance industry so that the risks are captured by those best equipped to evaluate them. We are convinced that tort law is too slow, too expensive, and too stifling of innovation to be an efficient remedy for the emerging problems.

These problems will not go away, but will only be exacerbated by the combined effects of delay, new technology, new pollutants, and tighter construction. Because the construction industry is too fragmented to carry out the research needed and because it is primarily a health problem, we feel that the federal role is critical in focusing on the real problems and in funding the required research. Our organization, the National Indoor Environmental Institute, stands prepared to share data and perspectives, and assist in planning or research. The problems are real, and that is why we are investing our own limited resources in this effort.

Sincerely,

Harvey M. Sachs, Ph.D.
Technical Director

HMS/mw

TESTIMONY TO BE PRESENTED TO THE HEARING ON INDOOR AIR QUALITY OF THE HOUSE SCIENCE AND TECHNOLOGY COMMITTEE

August 2 and 3, 1983

PART I: RADON IN HOUSES

R. E. Toohey, Environmental Research Division

J. Rundo, Office of the Director

PART II: EMISSION FACTORS OF KEROSENE HEATERS

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I. Radon in Houses

Introduction

Radon (^{222}Rn) is a naturally occurring radioactive gas which is continually produced by radium (^{226}Ra) which is present in trace amounts in soil. Although radon itself is chemically inert, it produces radioactive daughter products (isotopes of polonium, bismuth, and lead) which can be inhaled, deposited in the lungs, and thereby irradiate lung tissue.

The current worldwide interest in radon in residences stems from a combination of several factors. There appeared to be a linear relationship between incidence of lung cancer in uranium miners and exposure to radon daughters. This was an important consideration in directing attention to the exposure indoors of the entire population to radon at concentrations generally thought to average about 1 pCi litre^{-1} (37 Bq m^{-3}). The corresponding annual dose of about 0.1 rad yr^{-1} (derived from the basic assumptions of an equilibrium factor, F, of 0.5, an 80% house occupancy factor, and an equivalence of 0.5 rad per Working Level Month[*]) was combined with one of several suggested risk factors derived primarily from the data on the uranium miners, and with the size of the population, to yield estimates of lung cancer incidence which ranged from substantial fractions of the total observed, down to about 4000 per year for the United States. Added to this was the realization that reductions in ventilation rates of houses for economy in energy consumption would in all probability increase radon concentrations indoors and consequently the exposure of the population.

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[*] The Working Level is a unit for expressing the concentration of non-equilibrium mixtures of short-lived radon daughter-products in a dosimetrically useful manner. It is defined as a concentration of the daughters with a potential alpha-particle energy of 1.3 x 10^{-5} MeV litre^{-1} (2.08 x 10^{-5} J m^{-3}); this is the potential alpha-particle energy concentration of short-lived daughters in air which are in equilibrium with radon at a concentration of 100 pCi litre^{-1} (3.7 kBq m^{-3}). A Working Level Month is an exposure to one WL for 168 hours.

Radon

We have made measurements of radon in samples of air from 129 conventional homes in 36 communities or towns, mostly in the west suburban area of Chicago, and in 7 earth-shielded houses in six towns. In 19 houses, only a single "grab" sample of air was taken from a region (e.g. crawl space, or sump) that was not part of the living area, so our database really consists of 110 houses. We find that 24% of these houses have radon concentrations in excess of 3 pCi litre^{-1} (111 Bq m^{-3}), 15% greater than 6 pCi litre^{-1} (222 Bq m^{-3}), and 6% greater than 10 pCi litre^{-1} (370 Bq m^{-3}). The level of 3 pCi litre^{-1} is that proposed by the EPA as an upper limit for radon in houses (0.015 Working Level, at 50% equilibrium = 3 pCi litre^{-1}); the level of 10 pCi litre^{-1} was that set by the Surgeon General as indicating the need for remedial action to reduce radon levels in houses in Grand Junction, Colorado, built on uranium mill tailings (0.05 Working Level, at 50% equilibrium = 10 pCi litre^{-1}).

Radon daughters

However, our research into the behavior of radon daughters in indoor air has shown that the common assumption of a 50% equilibrium factor may frequently be an over-estimate. For a series of 81 hourly observations in a frame house during early autumn, the mean value of F was 0.22 ± 0.01, with a range of 0.11 - 0.44. For 93 observations over four days in another frame house during the late winter, the mean was 0.085 ± 0.003 with a range of 0.04 - 0.23. On the other hand, we observed a value of 0.50 ± 0.09, with a range of 0.19 - 0.83 for 6 observations in the latter house made during four days in July when the house was well ventilated with outside air. Wicke and Porstendörfer developed a theoretical treatment of the problem which seemed to explain most of the experimental observations (1). The most relevant aspect of their analysis is that the equilibrium factor is strongly dependent on the airborne concentration of particles. We have made some measurements of the particle concentrations in some of the houses that we have studied and observed unusually low values, e.g. $2 \times 10^3\ cm^{-3}$ in the first house for which data were given above. According to the theory this should result in an equilibrium factor of a little less than 0.2. This is in fact about what we have frequently observed. There is a tendency for our values for F to be lower in winter months. The possible role of static electricity at these times has not been investigated, but it might be expected to have an effect.

To summarise the situation for radon daughters, it is clear from the above that we cannot assume a value of 0.5 for the equilibrium factor without a considerable degree of over-estimation in many cases. While the results of the theoretical and experimental investigations of Wicke and Porstendörfer (1) seem to explain in large measure the behaviour of the daughers, the conditions they assumed or observed may not be universally applicable to houses in this country because of different conditions.

Conclusions

The data from Grand Junction may be used to put the question of radon in houses in perspective. Data collected prior to 1981 for 310 homes in Grand Junction (2) are summarized in the Table, where they may be compared with our results for 110 houses. The point to be made is that if our figure of 6% of houses showing more than 10 pCi litre^{-1} is representative of all houses in this country, there are far more people in the general population who are being exposed at these higher levels than there are in Grand Junction and all similar areas combined. Consequently, the contribution to the collective effective dose equivalent from "technologically enhanced" radon levels is a small fraction of the total from radon and its daughters. This points up the need for much more extensive data.

TABLE. Numbers of houses with high concentrations of radon in Grand Junction, Colorado, and near Argonne, Illinois.

Place	No. of Houses	% of Houses with Air Exceeding 6 pCi Litre^{-1}	% of Houses with Air Exceeding 10 pCi Litre^{-1}
Grand Junction, CO			
before cleanup	310	71	40
after cleanup		68	10
Chicago suburbs	110	15	6

References

1. Wicke, A. and Porstendörfer, J., "Radon Daughter Equilibrium in Dwellings," in Natural Radiation Environment, K.G. Vohra, U.C. Misra, K.C. Pillai and S. Sadasivan, eds., pp. 481-488, Wiley Eastern Limited, New Delhi (1982).
2. Franz, G. A., Colorado State Department of Health, personal communication.

II. Emission Factors of Kerosene Heaters

Introduction

The use of kerosene heaters in homes and commercial establishments has increased dramtically within a few years, with sales rising from about 3,400 units in 1974 to about six million by 1982 (1). The purchase of two of these units by a group at our facility and questions from several other groups about applications prompted us to investigate the extent of combustion product emissions.

In March 1982 limited information was available on combustion products emitted; it was decided to measure emission factors for our heaters; that is, the quantity of combustion products released per unit of fuel consumed. This was expanded to cover both radiant (R) and convective (C) types of heaters and the low sulfur (0.04% maximum) ASTM grade 1-K and the higher sulfur (0.3% maximum) 2-K grade fuels (2). Our results and those of other studies indicate the potential for exceeding short term EPA and American Society for Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards. Even if none of these products was produced, ventilation is needed to control carbon dioxide build-up. Where extra ventilation is required in a tightly sealed building, the effective efficiency of unvented heaters is reduced.

Results

For each test, the heaters were centered under a canopy-type hood enclosed on three sides. The heater was raised so that the top of the unit was about three inches above the top edge of the hood which was ventilated to capture all of the combustion products. The dilution ventilation rate was measured with an orifice plate in the exhaust duct. Sampling probes were mounted in the ventilation duct to sample for carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), formaldehyde (HCHO), hydrocarbons, and particulates. Fuel consumption was measured volumetrically and the heat input calculated based on 141,500 kJ/gal (134,200 BTU/gal). Heaters were operated for a ten minute warm-up period before sampling was begun. The heaters used were not new, but all had been in service for one season or less.

Table 1 gives the emission factors observed in units of micrograms produced per kilojoule of heat input in the fuel. In addition, operation of the heaters produces carbon dioxide (CO_2). Using an approximate but reasonable combustion formula for the hydrocarbon content of kerosene, one could expect production of about 187 cubic feet of carbon dioxide per gallon of kerosene burned. This information was used to calculate an emission factor for carbon dioxide of 67,100 µg/kJ by assuming heat production of 141,500 kJ/gallon. Then, for steady operation of a heater, a ventilation requirement of about 93 cfm would be needed per 10,000 BTU/hr to maintain the ASHRAE. Indoor Air Quality Limit of 2,500 ppm (3). Our result is within the range of the values measured by Traynor et al (4), who reported CO_2 emission factors of 66,200 - 78,000 µg/kJ.

Table 2 gives the calculated ventilation rates in cubic feet per minute (CFM) of make-up air required to maintain specified air concentrations of pollutants (TWA = time-weighted average) for a 10,000 BTU/hr heater. Note that the OSHA limits are included for comparison only; these limits would not be appropriate for residences. Similarly, the EPA annual limits listed would not be appropriate for comparison unless one measured or calculated exposures on an annual basis. Finally, the actual resulting concentrations could be higher or lower than the calculated values depending on the extent to which the outdoor makeup air is polluted with the same compounds, and the extent to which indoor furnishings and construction materials provide a sink by reacting with compounds such as nitrogen dioxide and sulfur dioxide.

Conclusions

The conclusions derived from this study are listed below:

1. More CO was produced from 2-K than 1-K fuel with both heater types.

2. High sulfur 2-K fuel produced more SO_2 than 1-K fuel.

3. Convective heaters produced about 3 times as much NO_2 as radiant heaters, except for the large convective unit C6.

4. Type of fuel had no significant effect on NO_2 production.

5. Relatively small amounts of formaldehyde were produced; control of other products should control HCHO.

6. Calculated CO_2 emissions indicate that about 100 CFM dilution ventilation is needed per 10,000 BTU/hr.

7. Ventilation control of CO_2 to 2,500 ppm should prevent CO, HCHO and particulates from exceeding ASHRAE limits providing outside concentrations are not high.

8. Control of SO_2 and NO_2 could require more ventilation to meet short-term air quality standards, depending upon fuel type, heater type, ambient levels, and loss to furnishings.

9. Combustion particle size is predominantly sub-micrometer from normally operating heaters.

We believe additional study is needed to assess the extent of exposure and resulting health effects associated with various combustion devices.

References

1. Consumer Products Safety Commission Briefing Concerning the Status of Kerosene Heaters, Washington, D.C. (October 27, 1982), p. 39.
2. Standard Specification for Kerosene, ASTM D3699-78, American Society for Testing and Materials, Phila., PA (1978).
3. Ventilation for Acceptable Indoor Air Quality, ASHRAE 62-1981, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta, GA (1981).
4. Traynor, G.W., et al, "Pollutant Emissions from Portable Kerosene-Fired Space Heaters," Report LBL-14301, Lawrence Berkeley Laboratory (April 1982).

TABLE 1. Pollutants Emissions Factors for Kerosene Heaters.

		CARBON MONOXIDE			SULFUR DIOXIDE			NITROGEN DIOXIDE			FORMALDEHYDE			RESPIRABLE PARTICULATES		
HEATER	FUEL	n	Factor	St.Dev.	n	Factor	St.Dev.	n	Factor	St.Dev.	n	Factor	St.Dev.	n	Factor	St.Dev.
R1	1-K	2	75.66	± 12.80	2	4.73	± 0.32	2	5.87	± 0.10	2	0.47	± 0.04			
R2	1-K	3	95.2	± 40.92	3	7.76	± 2.16	3	3.76	± 1.53	2	0.18	± 0.04	3	1.32	± 0.42
C5	1-K	3	122.77	± 12.77	3	3.89	± 1.23	3	20.73	± 5.17	3	0.45	± 0.12			
R1	2-K	4	159.6	± 24.6	4	46.67	± 22.26	4	4.05	± 1.69				4	3.58	± 0.86
R2	2-K	2	171.15	± 10.11	2	39.4	± 13.15	2	7.1	± 0.52	1	0.53		1	5.1	
R3	2-K	5	221.3	± 47.98	4	34.37	± 4.54	4	5.98	± 1.36				3	1.32	± 0.87
C4	2-K	2	212.85	± 42.21	1	33.2		2	15.55	± 2.47				2	3.93	± 1.62
C6	MIXED 1-K, 2-K	3	134.	± 9.85	2	27.7	± 18.95	3	4.11	± 0.36	3	0.02	± 0.014			

TABLE 2. Ventilation Requirements to Meet EPA/ASHRAE Standards (CFM per 10,000 BTU/Hr).

Pollutant	Heater Type	Fuel Type	Emission Factor µg/kJ	24-Hr TWA $\mu g/m^3$	Make-up Air CFM	Annual TWA $\mu g/m^3$	Make-up Air CFM
CO	Both	1-K	101	40,000[a]	16	10,000[b]	63
		2-K	193		30		120
SO_2	Both	1-K	5.6	365	94	80	430
		2-K	39.6		673		3070
NO_2	R	Both	5.2	5640[c]	5.7	100	320
	C	Both	18.7		21		1160
HCHO	R	1-K	0.33	2450[d]	0.8	120[e]	17
	C	1-K	0.45	-	1.1		23
Particulates	R	1-K	1.2	260	31	75	108
		2-K	2.9		69		240

[a] 1-Hr TWA

[b] 8-Hr TWA

[c] OSHA 8-Hr TWA

[d] ACGIH 8-Hr TWA

[e] ASHRAE 8-Hr TWA

Technical Council

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July 29, 1983

Honorable James H. Scheuer
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Washington, DC 20515

Dear Mr. Scheuer:

At the August 2 and 3, 1983 hearings on Indoor Air Pollution, I request your consideration of the attached position statement prepared by the TT-7 Committee on Indoor Air Quality and approved by the Executive Committee of the Air Pollution Control Association (APCA).

I am sure you are very familiar with APCA and know that this 77-year-old organization of over 8,000 members is a voluntary, cooperative, non-profit organization devoted solely to air pollution control.

The position statement was published in the May 1982 issue of the Association's journal, giving seven items as justification for the recommendations made then to the Congress. It is our belief that the issues set forth in this statement continue to be valid, and request that this letter and the attached statement be written into the record.

Sincerely yours,

James A. Frazier

James A. Frazier
Chairman of the TT-7 Committee

Attachment

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APCA Issues Position Statement On Indoor Air Quality

The Air Pollution Control Association has issued a position statement on the subject of indoor air quality. The statement was prepared by the TT-7 Committee on Indoor Air Quality and was approved by the Executive Committee of the Association on April 8, 1982. The statement follows:

I. Introduction

The Air Pollution Control Association (APCA), through its Technical Committee on Indoor Air Quality, has assessed the available scientific information on the adverse effects on human health owing to exposure to pollutants indoors. (For the purpose of this statement, the indoor environment is broadly defined as any enclosed space—e.g., individual residences, transportation terminals, and public buildings—whose environmental quality is not controlled by specific regulations, as is the case for workplaces and ambient outdoor air. Also, the term "pollutant" is used in its generic sense and its usage here does not address any legal issues that might be suggested by definitions in existing statutes or regulations.)

II. Recommendations

Congress is herewith requested by the Air Pollution Control Association (APCA) to address the importance of indoor air quality by drafting specific amendments to the Clean Air Act to:

- Authorize and appropriate funds to ensure the continuation of research on the indoor air quality in such areas as technical monitoring and problem assessment to resolve competing policies.
- Authorize and appropriate funds to undertake a health effects assessment program.
- Authorize and appropriate funds to establish and support a national data base and information clearing house with appropriate scientific staff. This staff would advise state and local governments and the private sector engaged in research on indoor health effects, including building practices related to energy conservation and pollution control.

III. Justifications

APCA's position has been formulated on the basis of the following findings:

- The presently available scientific information shows that some pollutants known to be hazardous to human health are found indoors. Some of these are emitted by primary sources indoors, such as unvented combustion units.
- People in the United States spend a significant percentage of their time indoors. Some people spend 100% of their time indoors, making their indoor exposure time far greater than that of persons exposed in the workplace or in the ambient air outdoors.
- In some instances, the indoor environment is the most significant source of human exposure to a pollutant, e.g., radon, asbestos, and tobacco smoke. Epidemiologic studies of health effects resulting from pollutant exposure most often do not include the exposures suffered by humans indoors, thus they do not determine the *total* exposure from all three environments: indoors, outdoors and workplace.
- Susceptible human subpopulations at greatest health risk owing to exposure to hazardous indoor pollutants include pregnant women, both healthy and unhealthy newborn infants, children, and aged persons.
- Some energy conservation efforts and building practices (sealing openings and reducing air-exchange rates between indoors and outdoors) can adversely affect the quality of the indoor environment.
- During outdoor air pollution alerts, the indoor environment may not be a safe refuge or escape. The same pollutants found in the *workplace* or in the *outdoor* ambient air may also be found in the indoor environment; thus, exposure to pollution in all three environments may be additive.
- There is no national clearing house wherein *collective* scientific information or expertise about the nonworkplace indoor environment is available for use by academic or private research organizations, medical or health care personnel, the general public, or state and local governments. Although several government agencies have information about some indoor pollutants no national data base exists.

PRESENTED AT THE 5th WORLD CONFERENCE ON SMOKING & HEALTH, WINNIPEG, CANADA, July 10-15, 1983

TOBACCO SMOKE AND THE NONSMOKER

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INTRODUCTION AND HISTORICAL PERSPECTIVE

It has long been known that high levels of smoke from factory chimneys could cause illness and death during air pollution episodes, and that elevated levels of smoke were epidemiologically implicated in chronic respiratory morbidity. For this reason, laws such as the U.S. Clean Air Act were passed in order to protect human health from the effects of outdoor air pollution, and National Ambient Air Quality Standards (NAAQS) were established. In the establishment of such standards it was explicitly assumed that air external to buildings was the only source of pollution, and that if this were cleaned up, public health would be protected from the ravages of air pollution.

It fell to two workers at the Naval Research Laboratory in Washington D.C. to demonstrate that second-hand smoke pollution from cigarettes, pipes, and cigars indoors was not only similar to the smoke from factory chimneys, but routinely occurred at far higher levels indoors than did factory smoke or automobile exhaust outdoors usually at levels exceeding the NAAQS (see figure 1). Furthermore, based on plausible scenarios for lifestyles with various exposures, there was reason to believe that many nonsmokers might be exposed to significant air pollution burdens, and by inference, risk of the diseases of smoking from regularly breathing indoor air polluted with tobacco smoke.[1] In April 1980, a scant month before this research appeared in the journal Science, James White, a physiologist, and Herman Froeb, a physician at the University of California in San Diego published a paper in the New England Journal of Medicine which made coast-to-coast headlines: after ten years of research on more than 2000 persons, they had concluded that long term exposure to indoor tobacco smoke, limited to the work environment only, was deleterious to the healthy normal nonsmoker, and significantly reduced small airways function to the same extent as smoking one to ten cigarettes per day.[2] The New York Times, in an editorial entitled "Thy Neighbor's Lungs", stated "That is not yet proof that the reduced lung function in an otherwise healthy body is medically important. Most victims were probably unaware of the impairment. But deterioration of the small airways in the lung does often precede lung disease. It is another reason, on top of earlier reasons, to prohibit smoking in indoor public places unless the smokers can be segregated so that they cannot jeopardize their neighbors."

Nearly a year later, the chief epidemiologist of the National Cancer Center Research Institute in Tokyo, Dr. Takeshi Hirayama, published an electrifying study of lung cancer mortality in 142,857 women which reported that nonsmoking women with smoking husbands developed lung cancer at a rate which was nearly double that of women whose husbands did not smoke.[3] The findings received world-wide attention. Sir Richard Doll, an internationally prominent British epidemiologist, commented that Hirayama's study was scientifically sound, and that the effect of passive smoking on nonsmoking wives was surprising, because it was larger than he would have expected. The implication, he said, is that cigarette smoking poses "a hazard to anybody in public rooms if they are not well ventilated." Four days later, *T New York Times*, in a piece entitled "Smoking Your Wife to Death", would editorialize "So much for the notion that second-hand smoke is merely a nuisance. The Japanese study, published in the authoritative *British Medical Journal*, adds to the growing evidence that second-hand smoke kills. The results strengthen the case for banning smoking in public places, especially where abstainers are exposed to smoke for long periods." The Tobacco Institute, the industry public relations organization, refused all comment. But behind the scenes, it retained a prominent statistician, Dr. Nathan Mantel, to find flaws in Hirayama's methods. In a memo to the Tobacco Institute, Mantel speculated that Hirayama had possibly made an error in a standard test of statistical significance; the Tobacco Institute widely publicized this speculation, but Mantel, in an interview, denied reaching a conclusion.[4] A voluminous correspondence filled the letters column of the *British Medical Journal* with Hirayama being both attacked and defended. The journal went to unusual lengths to air the controversy, even to the extent of publishing a letter from the Tobacco Institute.[5]

Meanwhile, two more papers were published which added further fuel to the controversy. Appearing almost simultaneously with the Japanese work was a small and little-publicized but well-crafted study of a few hundred Greek women by Trichopoulos, et al.[6], published in the International Journal of Cancer. Like Hirayama, the authors also found a statistically significant doseresponse relationship which showed that the nonsmoking wives of smoking husbands suffered lung cancer at approximately double the rate as their counterparts with nonsmoking husbands.[6] However, five months later, Lawrence Garfinkel, chief epidemiologist of the American Cancer Society, published a paper in the Journal of the National Cancer Institute which examined lung cancer in 176,739 nonsmoking women as a function of their husbands' smoking habits.[7] Although a small positive result was obtained, it did not attain statistical significance, and no dose-response relationship was observed. Garfinkel concluded that any effect of passive smoking, if any, on lung cancer was very small. Hammond and Selikoff[8] in reviewing the three lung cancer studies, observed that any effect of confounding variables such as exposure to passive smoking not related to husbands' habit, for example, in the workplace, was likely to be less in the more traditional societies of Japan and Greece than in the U.S., and that the U.S. study was not designed to detect an effect of passive smoking.

Nevertheless, the Tobacco Institute widely advertised the U.S. study as a refutation of Hirayama's work, and the Medical World News carried the headline, "On Passive Smoking: Cancer Society and Tobacco Institute in Rare Unity".[4] The U.S. Surgeon General in considering the weight of all of the studies, concluded: "In recent months, the popular press has generated interest in the controversy of whether passive or involuntary smoking causes lung cancer in nonsmokers. Three epidemiological studies examined this issue in the past year. ... While the nature of this association is unresolved, it does raise the concern that involuntary smoking may pose a carcinogenic risk to the nonsmoker. ... Therefore, for the purpose of preventive medicine, prudence dictates that nonsmokers avoid exposure to second-hand tobacco smoke to the extent possible."[9] This judgement was shared by the U.S. National Academy of Sciences.[10]

Very recently, in a paper published in the American Journal of Epidemiology, three workers in the French Cooperative Study PAARC[11] found that nonsmoking spouses of smokers of at least 10g of tobacco a day suffered impairment of mid-expiratory flow after 15 years of exposure to their spouses' smoking, and that the effect was particularly clear in the large subgroup of women without paid work, confirming the conclusions of White and Froeb.[2]

In sum, there is now evidence, some of it conflicting, that indirect exposure to tobacco smoke, so-called passive or involuntary smoking, the breathing of indoor air polluted with tobacco smoke, like outdoor air polluted with factory emissions, may cause cancer and respiratory impairment.[1,12] Moreover, there is a superabundance of evidence that direct exposure to tobacco smoke, i.e., active smoking, is "the largest preventable cause of death in America," causing an estimated 346,000 excess deaths per year from cancer, cardiovascular disease, and chronic pulmonary disease.[13] The major prospective studies on smoking and disease show that the risks of the diseases of smoking are related to the total dose delivered, regardless of the time pattern of exposure, that the disease risk increases with increasing depth of inhalation, and that there is no discernable threshold for any of the risks.[14] Since widespread knowledge of the dangers of tobacco smoke has been available since 1964, why then has the public health community been so slow to recognize the seriousness of the risks of passive smoking?[15] Perhaps the answer lies partly in the historic lack of quantification of nonsmokers' exposures to ambient tobacco smoke. The balance of this paper is devoted to a discussion and interpretation of recent research efforts towards rectifying this lack.

STUDIES DESIGNED TO QUANTIFY U.S. NONSMOKERS'EXPOSURE TO TOBACCO SMOKE

Exposure of nonsmokers to tobacco smoke might be expected to be common in the U.S. because one out of three U.S. adults smokes cigarettes at the estimated rate of 32 per day,[1] while an additional one out of six smokes cigars or pipes, and because indoor air pollution from tobacco smoke persists in indoor environments long after smoking ceases.[1,16,17]

Repace and Lowrey[1] presented a model of nonsmokers' exposure to the particulate phase of ambient smoke which was supported by controlled experiments and a field survey of the levels of respirable particles indoors and out, in both smoke-free and smoky environments; this phase contains 60 proven or suspect carcinogens.[9,13] This work, which established that ambient tobacco smoke imposed significant air pollution burdens on nonsmokers, was extended by later work[17] which further demonstrated the predictive power of this model, as demonstrated in fig. 2. The model predicts a range of exposure of from 0 to 14 mg of cigarette aerosol per day, depending upon the nonsmoker's lifestyle. Exposures of prototypical nonsmokers were modeled, but no attempt was made to estimate the average population exposure. It was shown that the concentrations of ambient tobacco smoke encountered by nonsmokers in a variety of microenvironments can, to good approximation, be estimated by knowledge of two factors: the average smoker density and the effective ventilation rate.[1] On the average, a characteristic value of the ratio of these factors can be assigned to a particular microenvironmental class, e.g., homes, offices, restaurants, etc.[18] Therefore, the average daily exposure of individuals can be estimated from the time-weighted sum of concentrations encountered in various microenvironments[10,18] containing smoke.

It is important to realize that most persons' lifestyles are such that they spend nearly 90% of their time in just two microenvironmental classes, thus affording a great simplification of exposure modeling. Szalai, as part of The Multinational Comparative Time Budget Research Project, which studied the habits of nearly 30,000 persons in 12 countries (1964-1966), has compiled data reporting the average time spent in various locations or microenvironments. Szalai's data for 44 cities in the U.S. was reorganized by Ott[19] who showed that U. S. urban dwellers spend an average of 88% of their time in just two microenvironments: in homes and in workplaces; moreover, employed persons in the U. S. cities were estimated to spend only 3% of the day outdoors while housewives spent only 2% outdoors. Repace and Lowrey[16] used these data to model the average exposures typical nonsmokers might receive in the two most-frequented microenvironments.

MODELED EXPOSURE OF NONSMOKERS AT WORK

Exposure of the population to the particulate phase of cigarette smoke can be modeled to determine both range of concentration and exposure, which is the concentration multiplied by the average respiration rate of the exposed persons.[20]

Repace and Lowrey[1,17] have shown that the ambient concentration of tobacco smoke particles, Q, from cigarette smoking can be usefully represented by an equilibrium model based upon occupancy of a space by habitual smokers who smoke 32 cigarettes per day (for every three habitual smokers, there is one cigarette burning constantly),

$$Q = 217\ D_{hs}/C_a \qquad (\mathrm{ug/m^3}) \qquad [1] ,$$

where D_{hs} is the habitual smoker density in units of smokers per 100 m^3, and C_a is the effective air change rate in units of air changes per hour (ach). The model accurately predicts ambient concentations of cigarette smoke over a wide range of smoking rates and ventilation rates[1,16,17] (e.g., see fig. 2).

Ventilation rates given by the American Society of Heating, Refrigerating, and Ventilating Engineers (ASHRAE)[28] were useful in this model to predict observed concentrations of tobacco smoke in indoor microenvironments.[1,16,17] ASHRAE Standards are national consensus standards for ventilation rates in the U.S., and are tied to expected building occupancy. Thus, Eq. [1] offers the possibility of modeling the range of nonsmokers exposures to ambient tobacco smoke by inserting the ranges of occupancy and air change rate. Using this method, Repace and Lowrey[16] estimated that the workplace exposures range from 1.35 to 3.38 mg/8 hrs, for an estimated average exposure of 2.37 mg/8 hrs. This value is consistent with that estimated from the concentrations measured in a field survey of 23 commercial buildings in the Washington, D.C. and New York City metropolitan areas, which reported a mean concentration of 242 ± 238 ug/m^3, averaged over all of the buildings. Assuming an average inhalation rate of 1.47 m^3/hr (a rate corresponding to light work)[20] for those exposed yields an estimated exposure of 2.85 mg/8hrs, or at an inhalation rate of 0.99 m^3/hr (a rate corresponding to alternate sitting and light work),[20] an estimated exposure of 1.92 mg/8hrs. Thus, the exposure estimates are consistent with the limited observations available. Based upon the ratio of white collar to blue collar workers, and upon surveys of smoking policies of about 1000 U.S. corporations, large, medium, and small, Repace and Lowrey[16] estimated that the exposure probability of U.S. workers to on-thejob smoking was 63%, and that the average on the job exposure to passive smoking was 1.82 mg/day, when weighted for average hours per day worked.

For comparison, we now examine the estimated average exposure modeled for the domestic microenvironment.

MODELING EXPOSURE OF NONSMOKERS AT HOME

Similarly, by using data from time budget and census studies, Repace and Lowrey[16] estimated the average length of time a person spends in the home microenvironment. This time differs by gender and employment status. Taking into account the different amounts of time spent in the home by employed men, employed women, and homemakers, they estimated that the occupancy-weighted average number of cigarettes smoked in a typical U.S. home of 340 m^3 volume during a 16-hr waking day was equal to 22 cigarettes per day (CPD). Using this figure, Eq. 1 predicts, using a air exchange rate typical of that expected for U.S. dwellings, a concentration value in good agreement with measurements of respirable particles obtained in homes containing one smoker by the Harvard Six City Study by Dockery and Spengler[27] By multiplying by a respiration rate corresponding to that of alternate sitting and light work, Repace and Lowrey[16] estimated that a typical U.S. nonsmoker is exposed to an average inhaled exposure of 0.45 mg/day, with an exposure probability of 62%, assuming that occupancy of the home by smokers and nonsmokers is coincident.

MEAN ESTIMATED EXPOSURE TO A TYPICAL ADULT FROM THE MOST-FREQUENTED MICROENVIRONMENTS

Repace and Lowrey[16] estimated a probability-weighted average exposure to a typical U.S. adult by combining the estimated dose to U.S. adults exposed in the workplace and at home, by weighting the exposure received in each microenvironment by the probability of receiving it, assuming that the the probabilities are independent, i.e., that exposure at work is not correlated to exposure at home. Their results are summarized in Table 1.

Table 1. Estimated probabilities of nonsmokers being exposed to tobacco smoke at home and at work (Repace and Lowrey[16])

Probability of being exposed at work: 63%; Probability of not being exposed: 37%

Probability of being exposed at home: 62%; Probability of not being exposed: 38%

Estimated Daily Annual Average Probability of being exposed	(Rounded Values)	Estimated Daily Average Exposure Received	Estimated Daily Probability-Weighted Exposu
At work and at home:	63% x 62% = 39%	2.27 mg	.89 mg
Neither at work nor at home:	37% x 38% = 14%	0.00 mg	.00 mg
At home only:	37% x 62% = 23%	0.45 mg	.10 mg
At work only:	38% x 63% = 24%	1.82 mg	.44 mg
Total:	100%		1.43 mg/day

Table 1 suggests that the typical U.S. nonsmoker is in fact a passive smoker who receives an average exposure of 1.43 mg/day, and that very few (15%) persons in the general population appear to escape daily exposure to tobacco smoke. Table 1 further suggests that individuals having exposure both at home or at work constitute high exposure groups, with the workplace likely contributing more exposure than the home by a ratio of 4 to 1. These calculations imply that epidemiological studies of passive smoking should control for exposures both at home and in the workplace. Further, if passive smoking does create a risk of smoking-related disease, there may be disparities in incidence observable by comparing the more-exposed and less-exposed categories, but if these categories are not separated, as they were not in the American Cancer Society Study, a potentially large confounding factor has not been taken into account, particularly since 40% of U.S. women are in the labor force.[30] Although the Japanese and Greek studies also did not take working into account, as Hammond and Selikoff[8] have suggested, this factor may not be as important in such relatively traditional societies.

TRANSLATING EXPOSURE INTO DOSE

At this point, the estimated range of exposure has been established for typical U.S. nonsmokers as 0 to 14 mg/day, the typical workplace exposure has been estimated at 1.82 mg/day, the typical home exposure at 0.45 mg/day, and the typical exposure at 1.43 mg/day. These may be directly compared with the 1981 sales-weighted average tar level for U.S. cigarettes of 14 mg/day, or with the level of the lowest tar cigarettes on the market, 0.55 mg or with pre-1960 cigarettes of tar level greater than 30 mg, according to one's preference (Bock, et al,[24]) However, none of these comparisons express the dose of tobacco tar to the nonsmoker's bronchial epithelium, rather, they express the amount inhaled daily. It is of interest to calculate the dose received by a typical nonsmoker's lung in each of three cases: the worst case, the workplace, and the home.

Close association with smokers at work and at home may lead to repeated daily inhalation of tobacco smoke by nonsmokers. This is significant because repeated daily exposure of nonsmokers to indoor air pollution from tobacco smoke may lead to a buildup of tar in the lungs to an equilibrium amount which may far exceed the daily exposure. This is a direct consequence of the very long clearance times for fine-particle aerosols deposited in the lungs.[22] On a single-compartment model[10] for lung-clearance, the equilibrium level of tobacco tar in a nonsmoker's lungs is given[16] by $D_{eq} = \sigma \tau D_n$, where D_n is the daily nominal dose, τ is the mean life for pulmonary clearance (1.44 times the half-life), and σ is the fraction of inhaled aerosol deposited. We assume the values τ = 101 days[26] and σ = 11%, although a value as high as 20% has been reported.[27] In terms of our modeled D_n (a) of 1.82 mg/day for a typical nonsmoking worker, (b) of .45 mg/day for a typical nonsmoker at home, (c) 1.43 mg/day for a typical nonsmoker overall, and finally, (d) our worst case, 14.4 mg/day[1] for a nonsmoker working in a piano bar with a chain-smoking spouse, we calculate respectively, in units of mg of tobacco tar, an equilibrium dose to the bronchial epithelium of (a) 20 mg, (b) 5 mg, (c) 16 mg, and (d) 160 mg.

On this single-compartment equilibrium model, the estimated doses to the bronchial epithelium of regularly exposed passive smokers are equivalent to smoking between a third of a 1981 sales-weighted average tar cigarette per day and a half-pack per day. Expressed in terms of very low tar (0.55 mg) cigarettes, these equilibrium doses would range from nearly 1/2 pack to more than 14 packs per day. In view of the Surgeon General's[14] statements that there is no safe level of consumption of cigarette smoke, that there does not appear to be any threshold effect for any of the diseases of smoking, that risk is closely related to total dosage, regardless of the time pattern of exposure, and that even the lowest yield of cigarettes presents significant risks, dosages of this magnitude cannot be dismissed as inconsequential, being well within the range of observed effects in smokers.

Is there any evidence to support this concept? Earlier work[1] discussed anecdotal evidence, based on elevated aryl-hydrocarbon hydroxylase and pigmented alveolar macrophages, that this buildup appears to have been observed in two nonsmokers. Moreover, serum thiocyanate[23] and benzpyrene[24] levels in some nonsmokers have been found to be be comparable to the elevated levels typically found in smokers,[25] providing further evidence that doses to passive smokers may indeed be equivalent to those found in active smokers. This buildup phenomenon may account for findings by White and Froeb[2] Trichopoulos et. al.[6], and Hirayama[3], that the risks of passive smoking were considerable fractions of those of active smoking.

CONCLUSIONS

Nonsmokers exposures to ambient tobacco smoke can be estimated using an equilibrium model. Estimates of such exposures appear to be consistent with measurements of concentrations in various indoor microenvironments. Estimates of exposure probabilities indicate that passive smoking appears to be a widespread daily phenomenon which only 15% of nonsmokers of working age escape. The results also indicate that estimated average U.S. workplace-related exposures are about four times higher than estimated average U.S. domestic exposures.

A single-compartment model for the equilibrium dose of respirable aerosol to nonsmokers lungs resulting from regular passive smoking indicates that tobacco tar may accumulate to levels reaching an order of magnitude higher than nominal daily exposures. This phenomenon offers a possible explanation for the results of epidemiological studies of diseases caused by passive smoking which indicate risks which are substantial fractions of those of active smoking. Estimates of the average doses to nonsmokers from passive smoking at home and at work suggest that typical equilibrium doses from these two most-frequented microenvironments are 20 mg and 5 mg, respectively, and the overall probability-weighted dose to the typical nonsmoker appears to be about 16 mg. The worst-case equilibrium dose is estimated to be 160 mg of tobacco tar on the bronchial epithelium. The magnitude of these doses is equivalent in value to the exposure obtained in smoking from 1/3 to 11 sales-weighted average tar (14 mg) cigarettes* per day.

Cigarette smoking has been judged by the Surgeon General to be a major cause of cancers of the lung, larynx, oral cavity, and esophagus, and a contributory factor for the development of cancers of the bladder, pancreas, and kidney, to be causally related to coronary heart disease, and to be the leading contributory cause of death from chronic bronchitis and other lung disorders. The Surgeon General has also stated that there is no safe cigarette nor safe level of consumption.

Because nonsmokers' doses of tobacco smoke from involuntary smoking appear to be even on average well within the range of exposure of active smokers, there is good reason to believe that indoor air polluted with tobacco smoke poses a significant threat to the health of nonsmokers.

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*1981 value.

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†DISCLAIMER

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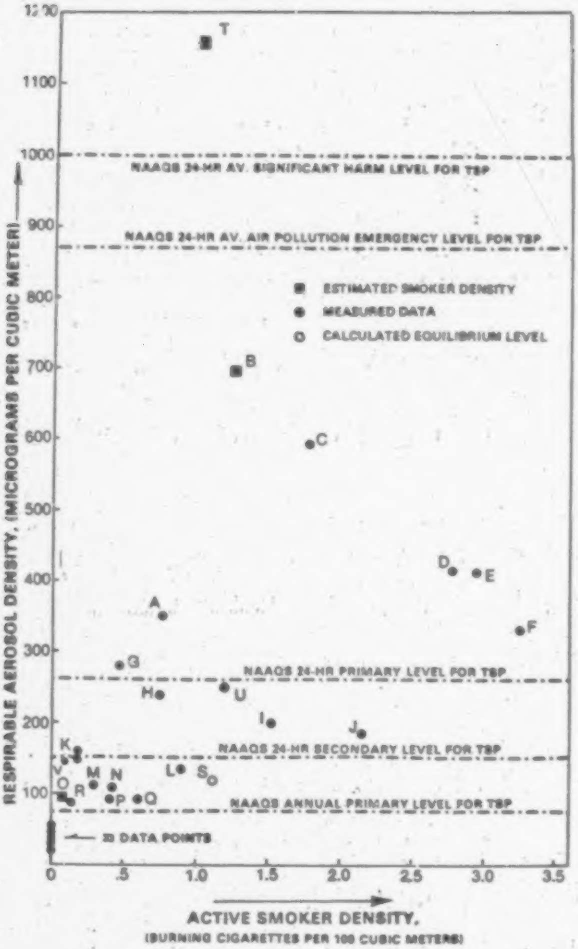

Figure 1. A field survey of respirable (< 3.5 μm) aerosol (RSP) in 56 microenvironments: indoors, outdoors, and in transit.[1,17,18] National ambient air quality standard levels (NAAQS) for Total Suspended Particulate (TSP) (<100 μm) are indicated for comparison. (The equivalent level in RSP for the annual primary standard would be about 40 μg/m^3.) The letters associated with each data point refer to buildings which are identified in the referenced publications. A conclusion which may be drawn from this survey is that exposure to tobacco smoking indoors is associated with significant air pollution burdens for nonsmokers.

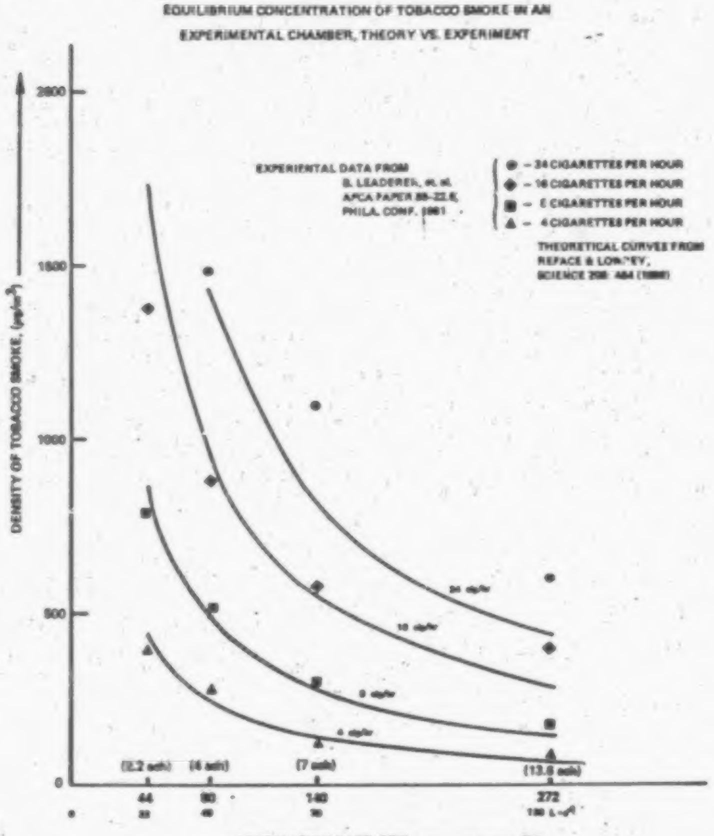

Figure 2. Equilibrium concentrations of tobacco smoke indoors generated by several smokers at The Pierce Foundation Laboratory at Yale University by Leaderer et al.[26] Eq.1 is used to generate the theoretical curves.[17] Eq. 1 has also been found to be useful in predicting the concentrations of tobacco smoke aerosol given in Fig. 1, using ASHRAE standards for ventilation based on occupancy.[1,17] Both the ventilation rates in cubic feet per minute (CFM) and the ventilatory air exchange rate in air changes per hour (ach) are given.

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HORACE R. KORNEGAY
Chairman

August 16, 1983

The Honorable
Don Fuqua
Chairman
Committee on Science and Technology
2321 Rayburn House Office Building
Washington, D.C. 20515

RECEIVED
AUG 17 1983
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Dear Mr. Chairman:

During the August 3, 1983 hearing on *Indoor Air Quality Research: Current Status and Future Needs* before the House Committee on Science and Technology, James Repace, an unscheduled Committee witness, testified on the nonsmoker's exposure to tobacco smoke and its possible health effects. Mr. Repace, an environmental policy analyst in air and noise pollution at the EPA who has neither medical training nor an advanced research degree in the field of indoor air quality, nevertheless claimed that tobacco smoke in the workplace presents an indoor air quality burden as well as a health risk to nonsmokers. Mr. Repace referred to several studies including his own for support; and he was subsequently asked to present copies of those studies for the Committee record. The paper submitted to the Committee by Mr. Repace, "Tobacco Smoke and the Nonsmoker," was recently presented to the Fifth World Conference on Smoking and Health (Winnipeg, Canada, July, 1983), an international conference of anti-smoking organizations.

Although one listening to the hearings or reading the transcript might conclude that Mr. Repace was testifying on behalf of the EPA before the Science and Technology Committee, it should be noted that he has previously expressly disclaimed any connection between his views on tobacco smoke and the nonsmoker and the official stance of the EPA on this issue. His paper delivered before the Fifth World Conference and requested by this Committee for its record contained the following disclaimer: "the opinions in this article are those of the author. No official endorsement by the EPA, or any other federal agency is intended or should be inferred."

In the interest of providing a balanced understanding of the issue regarding environmental tobacco smoke, we would therefore like to offer the following analysis and documentation for the record.

In his paper entitled "Tobacco Smoke and the Nonsmoker," Mr. Repace develops a theoretical model for estimating nonsmoker exposure to tobacco smoke in the workplace. He claims that his model is supported "by controlled experiments and a field survey." Mr. Repace suggests that his model demonstrates that a regularly exposed nonsmoker receives an estimated dose equivalent to that of smoking between a third of a cigarette to 10 cigarettes per day (one half to 14 packs per day of "low tar" cigarettes).[1]

Such enormous exposure and dose levels appear to have little basis in scientific fact. First, it should be noted at the outset that while Mr. Repace speaks in terms of dose estimates for the nonsmoker, a health effects specialist on indoor air quality recently wrote that "the specific contributions of sidestream smoke to personal exposures have not been documented."[2] Secondly, while a predictive model such as that proposed by Mr. Repace may serve as a general investigative aid, results based on such models are of questionable scientific merit without support from actual workplace exposure data. And although Mr. Repace suggests that his model is supported by his own actual data, serious deficiencies regarding his "field survey" methodology were raised at a symposium on "Ventilation and Indoor Air Quality" sponsored by The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in 1982.[3] For example, a consulting engineer noted that the "field survey" data failed to include measurements on actual ventilation rates, temperature and humidity -- variables which would be required to properly assess actual exposure data. Another critic pointed out that the data failed to distinguish between smoke particles from tobacco smoke and particulates from other sources. According to Dr. Theodor Sterling of Simon Fraser University in Canada, Mr. Repace failed to measure background levels of particles in the test areas before smoking began. Dr. Sterling suggested that the field study data therefore showed the highest correlation between particulate levels and the number of people occupying the premises -- not between particulate levels and the average number of smokers. This point indicates that indoor levels of particulates are greatly affected by dust raised by indoor traffic, cooking, and other human activity.

Other important research findings on environmental tobacco smoke are inconsistent with Mr. Repace's exposure model and his field survey data. Since particulates in the indoor environment are produced by many common sources, researchers consider nicotine a much more appropriate and reliable indicator for the presence of tobacco smoke, since it is produced exclusively by burning tobacco. Field studies which have used nicotine as a smoke index suggest that the actual contribution of tobacco smoke to the indoor environment is minimal.[4,5,6] For example, researchers from the Harvard School of Public Health found only very small amounts of nicotine in the atmosphere of bars, bus and airline terminals, restaurants and student lounges. Based on their data, the authors concluded that the typical average airborne concentration of tobacco smoke in public places to which the nonsmoker is exposed is less than 1/100 of a cigarette per hour.

Researchers in Europe who used different methods to measure the presence of tobacco smoke in the atmosphere reported slightly higher nicotine concentrations than did Drs. Hinds and First of Harvard. But they, like Hinds and First, concluded from their measurements that smoking did not represent a risk to nonsmokers. Other recently published literature on levels of tobacco smoke constituents in realistic settings tends to support the exposure levels determined by the Harvard research team. [7,8,9,10]

Further evidence regarding the minimal impact of tobacco smoke on the indoor environment has recently been published. In one study, the authors examined over 150 health hazard and indoor air quality evaluations for office buildings compiled by NIOSH, the CDC, and other agencies. After an examination of the data, the authors found that (1) average values of pollutants reported in buildings in which there were health related complaints did not exceed accepted workplace levels established by OSHA; (2) there appeared to be no substantial differences in pollutant levels between buildings where smoking is restricted or prohibited and where smoking is not restricted; (3) there was no difference in the prevalence of discomfort symptoms between buildings where smoking is restricted or prohibited and where it is not.[11]

A report from Lawrence Berkeley Laboratories arrived at similar conlusions after researchers tested the environment of an office building in Sacramento, California. [12] It is interesting to note that both office building studies reported particulate levels nearly three to four times lower than those reported by Mr. Repace. However, Mr. Repace surveyed densely populated public places such as game rooms, bars and restaurants, which do not necessarily typify average workplace environments.

During his remarks before the House Committee and again in his submitted paper, Mr. Repace referred to a study by Hirayama which reported that nonsmoking wives of smokers have a higher risk of lung cancer than nonsmoking women married to nonsmokers.[13]

Shortly after the Hirayama study appeared in the British Medical Journal, serious questions were raised in the medical literature about the design of the study and the validity of Hirayama's conclusions. A number of highly critical letters pointed out inadequacies and inconsistencies in the data.[14] In addition, after the publication of the Hirayama study, an American Cancer Society study concluded that nonsmoking women married to smokers exhibited no significant lung cancer risk when compared with nonsmoking wives of nonsmoking husbands. This conclusion was directly at odds with that of Hirayama.[15]

In the paper submitted for the Committee record by Mr. Repace, Hirayama reported additional health effects for nonsmoking wives exposed to their husbands' tobacco smoke.[16] However, during discussion of the Hirayama paper, Richard Peto of the United Kingdom (also referred to by Mr. Repace during his oral testimony before the Committee) said that Hirayama's data were "incredible" and that it was puzzling to find effects so large. Peto said that Hirayama's claims were very difficult to believe and that he remains doubtful of the study's basic causal claim.

His exposure model notwithstanding, the only data referred to by Mr. Repace in his discussion of workplace tobacco smoke exposures appeared in 1980 in an article by White and Froeb.[17] In that report, the authors claimed that chronic exposure to tobacco smoke in the work environment over long periods of time significantly affected lung function in nonsmokers. This study, however, also received severe criticism from a number of scientists and physicians.[18] Indeed, a high ranking government health official remarked in an editorial which accompanied the White-Froeb study that "the evidence that passive smoking in a general environment has health effects remains sparse, incomplete and sometimes unconvincing."[19]

Additional criticisms of the White-Froeb work surfaced during a joint annual meeting of the American Lung Association/American Thoracic Society in 1982. During a session on second-hand smoke exposures, Dr. Michael Lebowitz, a University of Arizona professor of medicine and co-author of the chapter on involuntary smoking and lung cancer in the 1982 Surgeon General's Report, termed the study improperly designed from an epidemiologic point of view. White and Froeb, Lebowitz argued, had unaccountably eliminated nearly 3,000 subjects from their study population and then declared their results significant. Lebowitz concluded that the result of the White-Froeb study should not be used to demonstrate an effect of environmental smoke on lung function. His remarks were reiterated in a letter published in the Congressional Record, December 16, 1982.[20]

Thus, much of the research on environmental tobacco smoke indicates that the actual contribution of tobacco smoke to the indoor environment does not approach the levels reported by Mr. Repace. More importantly, those studies relied upon by Mr. Repace regarding health effects from environmental tobacco smoke are seriously flawed and are inconsistent with other studies in the literature. [21,22,23,24]

Given the foregoing discussion, it would appear that efforts to measure and control indoor air quality by focusing on tobacco smoke exposures are misdirected and over-simplified. One example of the ineffectiveness of this strategy is particularly instructive. In 1981, the American Society of Heating, Refrigeration and Air Conditioning Engineers, promulgated a ventilation standard in which ventilation rates were based solely upon the criterion of the presence or absence of smokers within a given indoor setting. (ASHRAE 62-1981) However, the Standard received much criticism by scientists, engineers, architects and other professionals on the grounds that the prescribed ventilation rates were without adequate technical or scientific support. Thus far, the American National Standards Institute (ANSI) has rejected ASHRAE 62-1981 on the basis that the Standard lacked professional consensus. BOCA, the Building Officials and Code Administrators International, a model code organization serving some 27 states, overwhelmingly defeated a motion to include ASHRAE 62-1981 in its model building code. BOCA's rationale was that the disparate ventilation rates for smoking and nonsmoking areas were unjustified. Several weeks ago, the Department of Energy of the State of Minnesota withdrew consideration of the ASHRAE Ventilation Standard because the Department felt that it was not consistent with present model energy codes, and because Standard 62-1981 failed to demonstrate the inadequacy of ASHRAE's precursor ventilation Standard 62-73 to ensure indoor air quality.

Regarding the issue of indoor air quality, an internationally renowned indoor air quality specialist, Dr. P.O. Fanger, recently reported at a symposium on building energy management that, on the basis of his research, the ventilation rates specified for nonsmoking areas in ASHRAE 62-1981 are actually too low to adequately disperse even carbon dioxide (CO_2) and body odor.[25] The point here is obvious: a single-minded focus on tobacco smoke as the index for total indoor air quality tends to shift emphasis from other kinds of indoor air contaminants. This may result in a serious indoor air quality problem for areas in which smoking does not occur.

Thus, it appears obvious that the problem of indoor air quality is not to be solved through the narrow focus on environmental tobacco smoke. The sources of indoor air pollution are many and control measures are yet to be fully understood. Although more research in this area may be required, it is certain that, as one critic of Mr. Repace wrote, "the claim that smoking is responsible for indoor air pollution is an oversimplification of a complex, multisource problem."[26]

Sincerely yours,

Horace R. Kornegay

cc: The Honorable
James H. Scheuer

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26. See Reference 3.

PRESENTED AT THE 5th WORLD CONFERENCE ON SMOKING & HEALTH, WINNIPEG, CANADA, July 10-15, 1983

Passive Smoking and Lung Cancer

Takeshi Hirayama, M.D., Epidemiology Division,
National Cancer Center Research Institute, Tokyo

1. INTRODUCTION:

As reported previously(Brit. Med. J. 1981 282:183-185)(1), non-smoking wives of heavy smokers have a higher risk of lung cancer. A typical example, where a non-smoking wife with a heavy smoking husband died from lung cancer in 1966 after 40 years of marital life and later in 1978 the husband himself died of lung cancer, is shown in Table 1. Results of further follow-up study now reporting here not only confirms the validity of previous report but also reveals additional evidence for hazardous health consequences of passive smoking and provides new information suggesting the mechanism of carcinogenic action of long term inhalation of side-stream smoke.

2. MATERIALS:

The 16 years follow-up results of a census-population based cohort study for 265,118 adults(m: 122,261, f: 142,857) aged 40 years and above in Japan were analysed in detail to find out risk factors altering the risk of lung cancer and other major causes of death particularly in women.

3. RESULTS:

Non-smoking wives with smoking husband were found to carry a significantly elevated risk of nasal sinus cancer(n=28), lung cancer(n=200) and ischemic heart disease(n=494) by a large scale cohort study, 1966-81, in Japan. In these diseases the risk went up with the increase in number of cigarettes smoked by the husband.

3.1 Lung Cancer

A total of 429 death from lung cancer in women was recorded during 16 years follow-up(1966-81). Out of these 303 were non-smokers and 200 of these occurred among 91540 non-smoking married women whose husband's smoking habits were known. Detailed analysis was done with these cases taking into consideration possible confounding variables.

The standardized mortality ratio of lung cancer in non-smoking women was 1.00, 1.36, 1.42, 1.58 and 1.91 when husbands were non-smokers, ex-smokers, daily smokers of 1-14, 15-19 and 20 or more cigarettes per day respectively(one tail p value : 0.00178).(Fig. 1) The lower mortality ratio in non-smoking women with ex-smoker husband is impressive. It appears smoking cessation reduces not only own lung cancer risk due to active smoking but also lung cancer risk of partners due to passive smoking. Similar trend of risk elevation in non-smoking women with the extent of husband's smoking was observed in each time period of observation(Fig. 2), in each age group (Fig. 3), both by age of husbands and by age of wives(Fig. 4), in each occupational group(Fig. 5)(Table 2) and in each areas under observation(internal consistency). No other characteristics of husbands were found to elevate the risk of lung cancer in their non-smoking partners.(e.g. husband's drinking habit)(Fig. 6) The results are in line with a Greek study(2) (external consistency) but are somewhat at variance with an American Cancer Society study in the U.S.A.

Histology of 21 cases of lung cancer in non-smoking wives with smoking husband was not essentially different from that in smoking women(adenocarcinoma 57.1%, squamous cell carcinoma 19.0%, and small cell carcinoma 4.8%).

Non-smoking husband with smoking wife also showed an elevated risk of lung cancer, standardized mortality ratio being, 1.00, 2.14 and 2.31 in non-smoking wives, wives smoking 1-19 and 20 or more cigarettes daily respectively.(p : 0.0177) This observation also fortifies above listed evidence.

3.2 Nasal Sinus Cancer

A striking risk elevation of cancer of para nasal sinuses in non-smoking wives was observed according to the amount of husbands smoking, the standardized mortality ratio being 1.00, 2.27, 2.56 and 3.44 when husbands were non-smokers, smokers of 1-14, 15-19, and 20 or more cigarettes daily respectively(p : 0.01064).(Fig. 7)(Table 3) No other risk factors studied were identified to significantly alter the risk of nasal sinus cancer in women.(Fig. 8) Passive smoking appeares to be of unique importance. This new finding must strengthen the plausibility of carcinogenic hazards of side-stream inhalation through nose.

3.3 Other Cancers

In case of cancers other than lung(n=2484), a slight risk elevation was observed, standardized mortality ratio being 1.00, 1.06 and 1.11 when husbands were non-smokers, smokers of 1-19, and 20 or more cigarettes daily respectively.(p : 0.04590)(Table 4)

3.4 Emphysema and Chronic Bronchitis

A suggestive risk elevation of emphysema and chronic bronchitis(n=130) was observed with the increase in amount of smoking of husbands, standardized mortality ratio being 1.00, 1.29, 1.60 when husbands were non-smokers, smokers of 1-19, and 20 or more cigarettes daily respectively.(p : 0.05370) (Table 5)

3.5 Ischemic Heart Disease

A significant risk elevation with the increase in the extent of husband's smoking was observed with ischemic heart disease, the standardized mortality ratio being 1.00, 1.10 and 1.31 when husbands were non-smokers, smokers of 1-19 and 20 or more cigarettes daily respectively.(p : 0.01909)(Table 6) Similar results were obtained in the detailed analysis by age and occupation.(Table 7)

3.6 Effect of nutrition on the risk elevation of lung cancer and ischemic heart disease in non-smoking wives with smoking husband.

The risk reducing effect of daily intake of green-yellow vegetables on the risk of lung cancer, which was clearly observed in direct smokers(3), was studied in relation to passive smoking. The effect on lung cancer risk in non-smoking wives by smoking habit of husband was compared by dividing wives into daily and non-daily intakers of green-yellow vegetables. A statistically significant difference was observed between these two groups of women in the risk of dying from lung cancer.(Fig. 9, Table 8) The daily consumption of green-yellow vegetables was shown to lower to less than half the extent of elevation of lung cancer risk due to passive smoking. Similar observation was attempted for ischemic heart diseases but such risk reduction was not observed in women taking green-yellow vegetables daily.(Fig. 9) Since green-yellow begetables are rich in beta-carotine which possibly acts as promoter inhibiter (see R. Peto, R. Doll, J.D. Backley and M.B. Sporn, Nature, 290, 201-208), the observed results suggests that the influence of husband's smoking in lung cancer risk of non-smoking wives is of the nature of cancer promoters rather than cancer initiators. This might explain why such continuous but low dose exposure to passive smoking significantly elevates lung cancer risk in non-smoking wives. It is also understandable since influence of spouse smoking anyhow starts after reaching adult age. This, however, does not exclude the possibility of passive smoking acting as cancer initiators. In case of exposure to parents smoking in childhood such possibility must be high.

4. DISCUSSIONS:

The current results are in line with the results of measurements of various carcinogens in side-stream smoke(4)(5) and also compatible with known evidence showing hazardous influence of passive smoking including elevation of CO-Hb level and nicotine/cotinine level in blood after exposure to passive smoking, elevation of hydroxyproline level in urine (marker of collagen destruction in lung tissue), demonstration of small airway dysfunction in those daily exposed to passive smoking in work place(6), and risk elevation of pneumonia, bronchitis and asthma in children with smoking parent(s).(Table 9)

When the effects of passive smoking due to husbands smoking were compared with the effects of direct smoking in women, the results clearly indicated that the effect of passive smoking is less than one-half to that of direct smoking, standardized mortality ratio being 1.55 and 3.81 respectively. In terms of attributable risk, however, the effect of passive smoking on lung cancer in women is just as important as that of direct smoking as the population at risk is 4 times more in intrahousehold passive smokers(n=69645) than in active smokers(n=17366).(Fig. 10) Therefore, although the relative risk of indirect smoking was far smaller than that of direct smoking, the absolute excess deaths from lung cancer due to passive smoking must be quite important because of the large size of the exposed group especially in countries such as Japan where majority(70%) of adult men smoke but only minority (15%) of adult women smoke.

As described in my previous report, the age-adjusted mortality rates for lung cancer are on steep increase both for men and for women in Japan. As only a fraction of Japanese women with lung cancer smoke cigarettes, the reasons why their mortality from lung cancer parallels that in men have been unclear. The current study appears to explain at least a part of this long-standing riddle.

As also emphasized in my previous paper these observations strongly question the validity of the conventional method of assessing the relative risk of developing lung cancer in smokers by comparing with that in non-smokers. This study shows that non-smokers are definitely not a homogenous group and should be subdivided according to the extent of previous exposure to indirect or passive smoking. An example of observation of the effect of passive and active smoking on lung cancer risk in men and women was shown.(Fig. 11) Similarity of the effect of both active and passive smoking on lung cancer to each sex is impressive.

Finally, the results of the present study must effectively utilized in planning control programmes of lung cancer and other selected diseases. The results clearly indicate that lung cancer, especially in women, can only be controlled when proper measures are taken against passive smoking as well as against active smoking. Similar statement must be valid also with ischemic heart disease and emphysema and chronic bronchitis. In case of nasal sinus cancer since little influence of active smoking on the risk was observed, the role of controlling passive smoking must be of essential importance.

5. SUMMARY:

That non-smoking wives of heavy smokers have a higher risk of lung cancer reported in the previous paper was confirmed by further follow-up study of such women. The statement was found valid after considering most of possible confounding variables.

The risk of two other diseases, nasal sinus cancer and ischemic heart disease, in non-smoking women were also found to go up with the amount of husband's smoking. The former observation appear essentially important in considering carcinogenic potentials of side-stream smoke mainly inhaled through nose and the latter finding must be of importance in planning control programmes of another major killer of modern societies.

The current study revealed, in addition, the risk reducing influence of daily consumption of green-yellow vegetables on lung cancer risk in passive smokers just as in active smokers, suggesting nutrition might also could serve as a means for lung cancer intervention in addition to anti-smoking programmes. Similar effect of nutrition on the risk elevation due to passive smoking, however, was not observed with ischemic heart disease.

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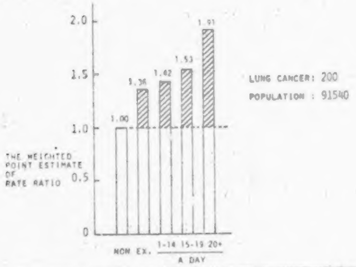
Table 1

	Husband	Wife
(1) Name :	Y. I.	T. I.
(2) Date of Birth :	March 4, 1902	July 20, 1904
(3) Cause of Death :	Lung Cancer	Lung Cancer
(4) Date of Death :	March 30, 1978	June 14, 1966
(5) Smoking Habit :	20 Cigarettes daily	None
(6) Address :	Yamamoto City, Wakari County, Miyagi Prefecture, Japan	
(7) Occupation :	Construction Worker	Housewife
(8) Age of Marriage:	22	20

Fig. 1

AGE STANDARDIZED MORTALITY RATE RATIO
FOR LUNG CANCER IN NON-SMOKING WIVES
BY SMOKING HABIT OF HUSBAND

PROSPECTIVE STUDY, 1966-81, JAPAN



HUSBAND'S AGE GROUP	HUSBAND'S SMOKING HABIT NON SMOKER		EX. SMOKER		1 - 14/D		15 - 19/D		20+/D		TOTAL	
40 - 49	4	6229	1	1255	8	8621	6	5150	16	10764	35	32027
50 - 59	10	7791	3	1922	20	9646	8	4052	24	9820	65	33253
60 - 69	18	7120	11	2687	28	7245	9	2513	23	4651	89	24216
70 - 79	5	755	2	348	2	612	1	105	1	226	11	2046
TOTAL	37	21895	17	6212	58	26144	24	11878	64	25461	200	91540
The weighted point estimate of rate ratio and test-based 90 percent confidence limits	1.00		$1.36<^{2.18}_{0.85}$		$1.42<^{2.01}_{1.01}$ $1.45<^{2.02}_{1.04}$		$1.58<^{2.50}_{0.98}$		$1.91<^{2.71}_{1.34}$		Mantel-extension chi 2.913 one-tail p value 0.00178	
Mantel-Haenszel chi one-tail p value	-		1.0855 0.1389		1.8298 0.0337				3.0293 0.0012			

Fig. 2

Standardized Mortality Ratio for Lung Cancer in Non-smoking Women
By Smoking Habit of the Husbands and By Years of Observation
(Prospective study, 1966-81) Japan

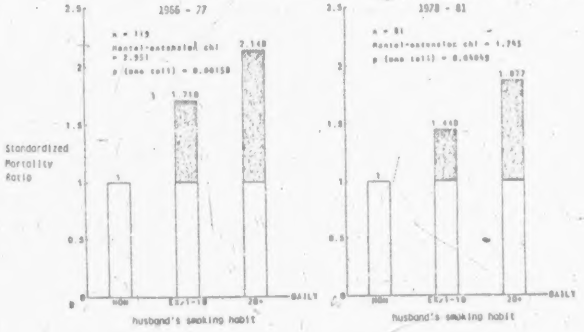


Fig. 3

Age Specific Mortality Rate per 100,000
in Non-Smoking Wives
By Smoking Habit of Husband

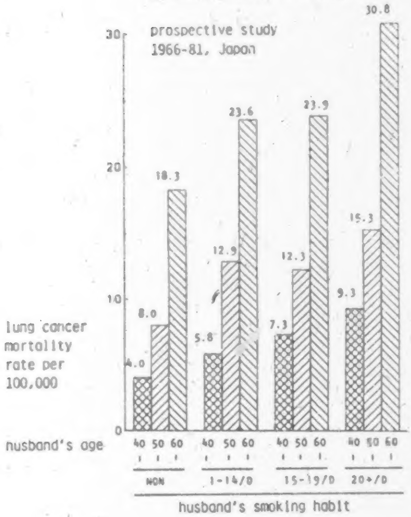


Fig. 4

Mortality Rate for Lung Cancer (per 100,000) in Non Smoking Wives
By Smoking Habit of Husband   Prospective study, 1966-81, Japan

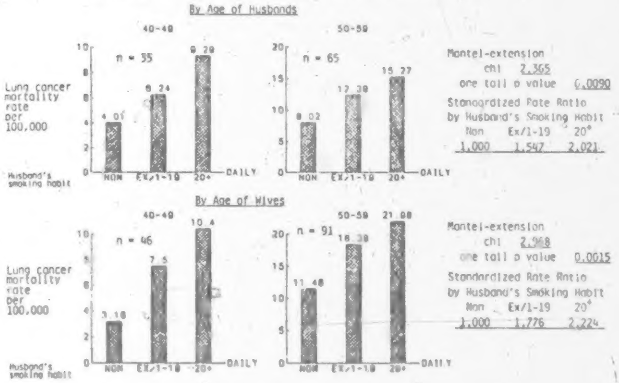


Fig. 5

Lung Cancer Mortality in Non Smokind Wives
by Occupation and Smoking Habit of the Husband

Prospective study, 1966-81, Japan

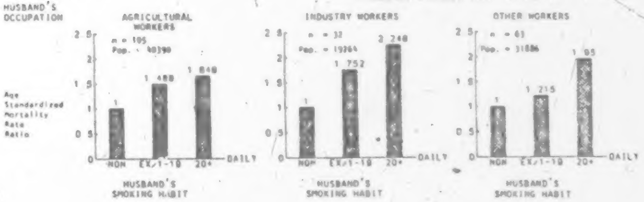
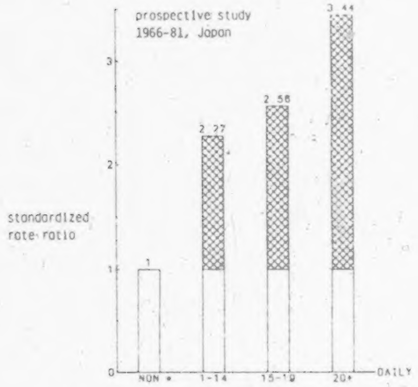


Fig. 7

Standardized Mortality Rate Ratio for Nasal Sinus Cancer in Non-smoking Wives By Smoking Habit of Husband



* including ex-smokers
Mantel-extension chi : 2.303
one tail p value : 0.01064

Table 3

MORTALITY FOR NASAL SINUS CANCER IN WOMEN
BY AGE GROUP, BY OCCUPATION AND BY SMOKING HABIT OF HUSBAND
(patient herself a non-smoker)
Prospective study, 1966-81, Japan

		non smoker*		1 - 14/D		15 - 19/D		20+/D		total	
husband's occupation	husband's age group	nasal sinus cancer	pop.	nasal sinus cancer	pop.	nasal sinus cancer	pop.	nasal sinus cancer	pop.	nasal sinus cancer	pop.
agricultural workers	40 - 49	0	3088	1	3807	1	1548	1	3636	3	12079
	50 - 59	1	4361	2	4381	1	1567	1	3514	5	13823
	60 -	2	6117	5	4058	2	1523	3	2241	12	13939
others	40 - 49	0	4396	0	4814	0	3610	1	7128	1	19948
	50 - 59	0	5352	1	5287	0	2485	1	6306	2	19430
	60 -	2	4793	0	3797	0	1095	3	2636	5	12321
	total	5	28107	9	26144	4	11828	10	25461	28	91540
standardized rate ratio :		1.000		2.270		2.562		3.440		mantel-extension chi 2.303 one-tail p value 0.01064	

* including ex-smokers

Fig. 8

Standardized Mortality Rate Ratio for Cancer of Nasal Sinus
in Nonsmoking Women by Selected Risk Factors

Prospective study, 1966-81, Japan

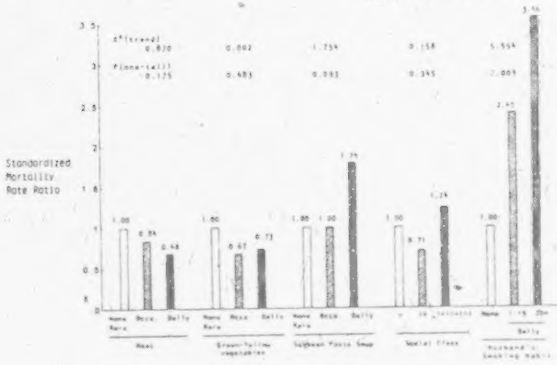


Table 4

MORTALITY FOR CANCER OTHER THAN LUNG IN WOMEN
BY AGE GROUP AND BY SMOKING HABIT OF HUSBAND
(PATIENT HERSELF A NON-SMOKER)
PROSPECTIVE STUDY, 1966-81, JAPAN

HUSBAND'S AGE GROUP	HUSBAND'S SMOKING HABIT						TOTAL	
	NON SMOKER		EX-SMOKER 1 - 19/D		20+/D			
40 - 49	83	6229	220	15034	161	10764	464	32027
50 - 59	177	7791	408	15642	246	9820	831	33253
60 - 69	316	7120	564	12443	230	4651	1110	24214
70 - 79	29	755	39	1065	11	226	79	2046
TOTAL	605	21895	1231	44184	648	25461	2484	91540
The weighted point estimate of rate ratio and test-based 90 percent confidence limits	1.00		1.06	1.15 0.98	1.11	1.22 1.01	Mantel-extension chi 5.686	
Mantel-Haenszel chi	-		1.3394		1.9191		one-tail p value	
one-tail p value	-		0.0902		0.0275		0.04590	

Table 5

MORTALITY FOR EMPHYSEMA, AND CHR. BRONCHITIS IN WOMEN
BY AGE GROUP AND BY SMOKING HABIT OF HUSBAND
(PATIENT HERSELF A NON-SMOKER)
PROSPECTIVE STUDY, 1966-81, JAPAN

HUSBAND'S AGE GROUP	HUSBAND'S SMOKING HABIT						TOTAL	
	NON SMOKER		EX-SMOKER 1 - 19/D		20+/D			
40 - 49	2	6229	12	15034	9	10764	23	32027
50 - 59	5	7791	16	15642	9	9820	30	33253
60 - 69	19	7120	32	12443	19	4651	70	24214
70 - 79	2	755	5	1065	0*	226	7	2046
TOTAL	28	21895	65	44184	37	25461	130	91540
The weighted point estimate of rate ratio and test-based 90 percent confidence limits	1.00		1.29	1.96 0.85	1.60	2.48 1.03	Mantel-extension chi 1.610	
Mantel-Haenszel chi one-tail p value	-		0.9921 0.1606		1.7641 0.0389		one-tail p value 0.05370	

* : 60-69 and 70-79 were pooled.

Table 6

MORTALITY FOR ISCHEMIC HEART DISEASES IN WOMEN
BY AGE GROUP AND BY SMOKING HABIT OF HUSBAND
PROSPECTIVE STUDY, 1966-81, JAPAN

HUSBAND'S AGE GROUP	HUSBAND'S SMOKING HABIT						TOTAL	
	NON SMOKER		EX-SMOKER 1 - 19/D		20+/D			
40 - 49	13	6229	40	15034	33	10764	86	32027
50 - 59	26	7791	56	15642	49	9820	131	33253
60 - 69	65	7120	125	12443	47	4651	237	24214
70 - 79	14	755	19	1065	7	226	40	2046
TOTAL	118	21895	240	44184	136	25461	494	91540
The weighted point estimate of rate ratio and test-based 90 percent confidence limits	1.00		1.10	1.33 0.91	1.31	1.63 1.06	Mantel-extension chi 2.073	
Mantel-Haenszel chi one-tail p value	-		0.8504 0.1976		2.0723 0.0191		one-tail p value 0.01908	

Table 7

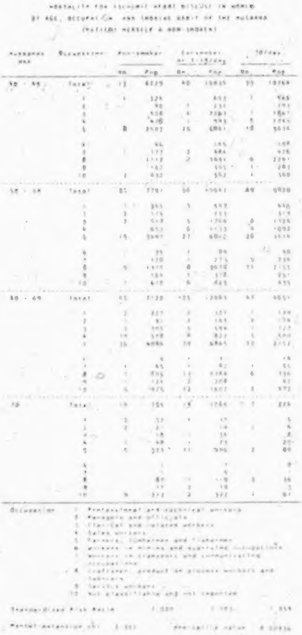


Table 8

EFFECT OF DAILY INTAKE OF GREEN-YELLOW VEGETABLES ON LUNG CANCER MORTALITY IN NON-SMOKING WIVES WITH SMOKING HUSBAND

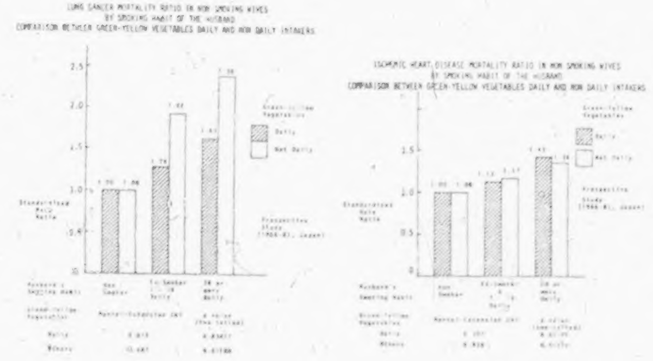
HUSBAND'S SMOKING HABIT		EX-SMOKER OR 1-19/DAY				≥ 20/DAY			
WIFE'S EATING HABIT		GREEN-YELLOW VEGETABLES							
		DAILY		NON DAILY		DAILY		NON DAILY	
HUSBAND'S		POP.	LUNG CA.	POP.	LUNG CA.	POP.	LUNG CA.	POP.	LUNG CA.
OCCUPATION	AGE								
AGRICULTURE	40-49	5050	5	891	1	3037	7	599	2
	50-59	5196	11	1616	5	2588	9	926	0
	60-69	5106	22	1739	11	1588	6	564	4
	70-79	287	1	159	0	45	0	44	0
OTHERS	40-49	7288	8	1805	1	5377	5	1751	2
	50-59	6732	12	2098	3	4633	5	1673	10
	60-69	4088	9	1510	6	1906	10	593	3
	70-79	371	1	248	3	81	1	56	0
TOTAL		34118	69	10066	30	19255	43	6206	21

MANTEL-HAENSZEL CHI = 1.986
P (ONE TAILED 0.047)

ODDS RATIO : NON DAILY GREEN-YELLOW VEGETABLES INTAKERS 1.000
DAILY GREEN-YELLOW VEGETABLES INTAKERS 0.707
(STANDARDIZED RATE RATIO)

90 % CO IDENCE LIMITS 0.538 - 0.943

Fig. 9



LUNG CANCER MORTALITY RATIO IN NON SMOKING WIVES BY SMOKING HABIT OF THE HUSBAND COMPARISON BETWEEN GREEN-YELLOW VEGETABLES DAILY AND NON DAILY INTAKERS

ISCHEMIC HEART DISEASE MORTALITY RATIO IN NON SMOKING WIVES BY SMOKING HABIT OF THE HUSBAND COMPARISON BETWEEN GREEN-YELLOW VEGETABLES DAILY AND NON DAILY INTAKERS

Table 9

Passive Smoking is Harzardous to Health

1. Existence of toxic substances (including carcinogens) in sidestream smoke mostly at higher concentration than in mainstream smoke.
2. Existence of a large number of non-smokers who have to inhale sidestream smoke frequently for long years at home and/or at working place.
3. Existence of sidestream smoke component in blood and urine of non-smokers exposed to passive smoking(e.g. Nicotine, CO-Hb).
4. Existence of functional abnormalities in non-smokers exposed heavily to passive smoking(e.g. respiratory or circulatory function).
5. Lung tissue damage and destruction in chronic passive smokers as shown by elevated hydroxyproline excretion in urine.
6. Higher incidence of selected diseases in non-smokers exposed heavily to passive smoking(e.g. pneumonia, bronchitis, asthma, ischemic heart disease, lung cancer).
7. Experimental evidence.

Fig. 10

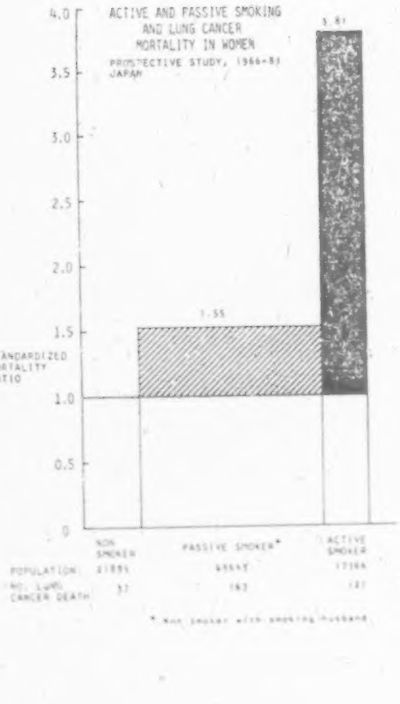
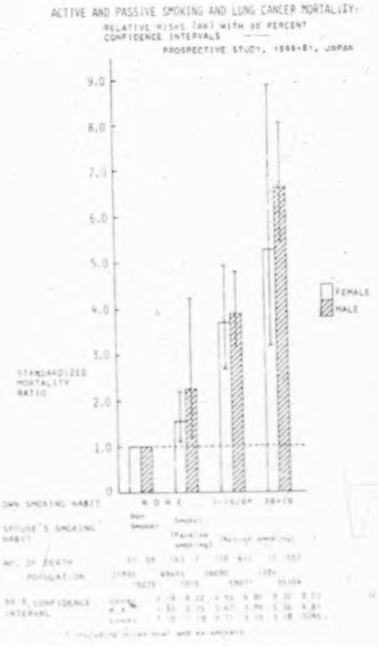


Fig. 11



Environment International, Vol. 8, pp. 83-87, 1982
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0160-4120/82/070083-05$03.00/0
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ASSOCIATIONS BETWEEN GRAB SAMPLE AND INTEGRATED RADON MEASUREMENTS IN DWELLINGS IN MAINE AND TEXAS

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Radon concentrations were measured in several locations in each of approximately 100 dwellings in central Maine and in Houston, TX. Integrated samples were taken during the heating (or cooling) seasons with commercially available passive alpha track devices, while grab samples were taken at the time of integrated sampler deployment. It was found that both indoor and outdoor measurements in both areas were distributed log normally, and that the geometric mean of indoor measurements in Maine was three times higher than that of corresponding measurements in the Houston area. It was also noted that the mean of the indoor grab sample measurements was not significantly different from the mean of the indoor integrated measurements, and that the degree of correlation between the grab samples and a given indoor integrated sample was nearly as good as between integrated samples taken at different living area locations.

Introduction

The design of environmental sampling programs frequently involves tradeoffs between the quantity and the quality of the data obtained. A continuous record of real-time measurements is considered superior to an integrated measurement over a comparable period, which is in turn superior to a small number of instantaneous grab samples taken during the period. Grab samples, on the other hand, are generally the least expensive of the options mentioned, and offer the additional advantage of prompt availability of data. Some relationships noted in a sampling program involving the latter two measurement methods are presented here, and possible implications for indoor sampling strategy are discussed.

Methods

The methods and primary data summarized here are described at greater length elsewhere (Prichard *et al.*, 1982). Approximately 100 dwellings in and around Houston, TX, were surveyed during the summer and fall of 1980 when most of the structures were using air conditioning. A similar number of dwellings in central Maine were surveyed the following winter during the heating season. The Houston dwellings were predominantly single-story slab-on-grade ranch houses or units in modern two- or three-story apartment complexes, while the Maine structures were for the most part two-story wood-frame houses with full or partial basements. Each house was equipped with three passive integrating radon detectors (Alter and Fleischer, 1981) in the living area and one detector in a sheltered outdoor location. A fifth detector was placed in the basement in the Maine group. At the time of dosimeter deployment, grab samples of indoor air and household water were taken in the Maine dwellings and, to a lesser extent, in the Houston dwellings. The grab samples were returned to the laboratory and analyzed with liquid scintillation techniques (Prichard, 1982; Prichard and Gesell, 1977). After an exposure period of 3-5 months, the integrating radon detectors were recovered and shipped to the vendor for analysis.

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Results

Figure 1 shows histograms of the average living area and outdoor integrating detector data for the Maine and Houston locations. It can be seen that indoor measurements are generally higher than outdoor measurements, and that both the indoor and outdoor values in Maine are considerably higher than those in Houston. It must be noted that the "outdoor" Maine values were taken in sheltered locations such as sheds and porches, and might not be fully representative of ambient outdoor readings. Another feature apparent in Fig. 1 is the appearance of a normal distribution when the data are plotted on a logarithmic scale. The appearance of log normality is verified in Fig. 2, which shows the Maine and Houston living area average data plotted on a probability scale. In both cases, the logarithms of the data fit normal distributions at the $p = 0.01$ level. Because the data are more log-normally than normally distributed, the geometric means and standard deviations were considered most appropriate for describing the results. Table 1 shows these values for the measurement sites and measurement methods for both the Maine and Houston data sets. The site labeled "optional" was generally in the first floor living area in the Maine group, and was in an out-of-the-way closet or pantry in the Houston group.

One set of data from a solar house in Maine was excluded from the collective analyses. The radon measurements ranged from 53 pCi/l in the bathroom to 133 pCi/l in the ballast room adjacent to the master bedroom. The exclusion of this structure was justified on the grounds that it was not representative of the general housing stock in the area and because the inclusion of values from it would unduly influence averages and correlations.

Tables 2 and 3 present the results of t-tests and correlations between the logarithms of the data from various measuring sites in Maine and Houston, respectively. The p-values obtained from a paired t-test for the equivalence of the means of the indicated measurement categories are shown in the upper right-hand portion of the matrix. For example, it is seen in the Maine group that the bathroom values are significantly ($p < 0.001$) higher than the bedroom values and are also higher than the first-floor measurements at the $p = 0.01$ level of significance. The first-floor and the bedroom measurements ($p = 0.72$) are not significantly different, nor are the grab samples different from the living-room measurements. The basement radon levels are unambiguously higher than the living-room levels, and the outdoor values are clearly lower.

Values of the correlation coefficient r are tabulated in a similar fashion in the lower left half of the matrix. Significance at the $p = 0.05$ level is indicated by a single asterisk, while significance at the $p = 0.01$ level is indicated by a double asterisk. In the Maine set it is seen that all indoor air and water measurements are correlated at the $p = 0.01$ level, with the exception of the water and basement air measurements, which are correlated at the $p = 0.05$ level. In contrast, the outdoor measurements are not significantly correlated with anything else at the $p = 0.05$ level.

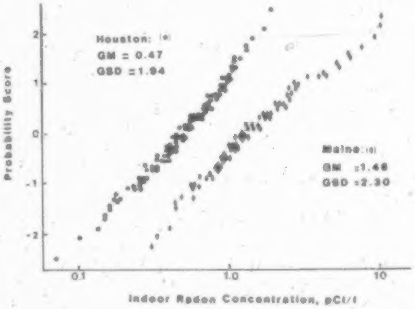

Fig. 2. Probability plots of average living-room radon concentrations in central Maine and Houston.

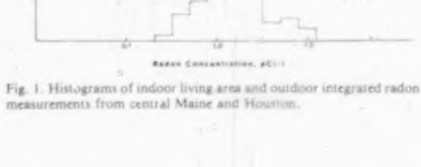

Fig. 1. Histograms of indoor living area and outdoor integrated radon measurements from central Maine and Houston.

Table 1. Geometric sample means and standard deviations of radon measurements taken at various sites in the two study areas.

	Central Maine			Houston		
	N	$\bar{X}$ (pCi/l)	S	N	$\bar{X}$ (pCi/l)	S
Bedroom*	81	1.12	2.40	103	0.39	2.46
Bathroom*	81	1.62	2.41	103	0.58	2.47
Optional*	82	1.40	2.43	101	0.47	2.67
Basement*	77	2.46	2.40	–	–	–
Outside*	67	0.46	2.42	81	0.22	2.55
Air grab	57	1.67	3.01	23	0.49	2.26
Water grab	83	5,860	5.60	14	1,084	1.66

*Taken with passive integrating radon detector (A'81).

Table 2. Matrix of correlation coefficients and t-test p-values for Maine radon measurements. Correlation coefficients are on the lower left, t-test p-values are on the upper right.

	Bedroom	Bathroom	First Floor	Air Grab	Basement	Outside
Bedroom		0.000	0.72	0.82	0.000	0.000
Bathroom	0.83**		0.01	0.22	0.000	0.000
First floor	0.85**	0.82**		0.90	0.000	0.000
Air grab	0.73**	0.74**	0.71**		0.011	0.000
Basement	0.71**	0.66**	0.60**	0.46**		0.000
Outside	0.08	0.07	0.12	0.15	0.18	
Water	0.51**	0.54**	0.50**	0.55**	0.33**	0.04

*Correlation significant at the $p = 0.05$ level.
**Correlation significant at the $p = 0.01$ level.

The contrasts in the Houston group are in general less striking than those in the Maine data, due in part to the generally lower radon levels and the reduced number of air and water grab samples. In lieu of basement data, PERM (Passive Environmental Radon Monitor) measurements are included in Table 3. The difference between all indoor and outdoor means is still highly significant, but the outdoor air measurements are correlated with the indoor measurements from at least the $p = 0.05$ level, which is in sharp contrast to the Maine data.

Table 4 was assembled to demonstrate the usefulness of the various measurement sets as predictors of the long-term integrated bedroom values. The intercept, slope, and the square of the correlation coefficient obtained from linear regression are ranked in descending order of r^2. The best predictors are the other two integrated living area sets, as might well be expected. The relation between the bedroom and first-floor integrated samples is shown graphically in Fig. 3. That plot can be compared with Fig. 4, which shows the air grab samples plotted against the integrated bedroom values. This comparison, along with the regression parameters from Table 4 and the t-test levels from Table 2, demonstrates the ability of grab sample data to characterize a communitywide exposure situation nearly as well as the more time-consuming methods.

Discussion

A number of characteristics of the Maine and Houston data sets will be emphasized at this point. First, the indoor values in both locations are markedly higher than the outdoor values. This is quite consistent with the general literature on indoor/outdoor relationships and is plausibly explained by the dwellings' retention of radon given off by the underlying soil, building materials, household water, and other sources. As ventilation is reduced in order to conserve energy, the indoor radon levels will be increased correspondingly.

A second notable feature of the data is the strong tendency toward log normality displayed by the distribution of indoor measurements in both locations. The log normality of indoor radon data has been noted by several observers in many locations (Scott, 1981; Sachs *et al.*, 1982; Alter, 1982; Gesell, 1982). The geometric means vary markedly from area to area, as is the case with the data reported here, but the log normal trend in individual data sets is pronounced. While certain anomalies due to construction materials and building styles are to be expected, it appears reasonable to hypothesize that indoor radon measurements from conventional housing in a given locale will fit a single log normal distribution. The definition of "locale" depends on several geological and other factors which can not be expected to coincide with political boundaries. Nevertheless, the available data suggests that in most cases a city or township is small enough to be considered a single "locale."

Given the working assumption of underlying log normality, a great deal of preliminary information can be obtained with a limited number of well-chosen grab samples, as long as due consideration is given to meteorological variables. Integrated or continuous data is

Table 3. Matrix of correlation coefficients and t-test p-values for Houston radon measurements. Correlation coefficients are on the lower left, t-test p-values are on the upper right.

	Bedroom	Bathroom	Closet	Air Grab	PERM	Outside
Bedroom		0.53	0.17	0.74	0.07	0.000
Bathroom	0.047		0.03	0.28	0.71	0.000
Closet	0.060	0.66**		0.25	0.06	0.000
Air grab	0.51**	0.76**	0.54**		0.20	0.16
PERM	0.52*	0.64**	0.48**	0.56**		0.000
Outside	0.39**	0.23*	0.27*	0.084	0.24*	
Water	0.62*	0.45	0.41	0.059	0.034	0.30

*Correlation significant at the $p = 0.05$ level.
**Correlation significant at the $p = 0.01$ level.

Table 4. Regression parameters of measurements used as predictors of bedroom radon concentrations (Maine data).

Site	d.f.	Intercept (pCi/l)	Slope	r^2
First floor	75	0.22	0.84	0.84
Bathroom	76	0.13	0.75	0.79
Air grab sample	44	0.71	0.59	0.66
Basement	69	0.66	0.33	0.50
Water grab sample	70	1.46	0.04*	0.11
Outdoor	60	1.78	−0.12	0.001

* pCi/l (air) per nCi/l (water).

clearly preferable if the object of a measurement program is to assess the dose commitment associated with a given structure. But if the primary objective of a survey is to identify areas in which radon might prove to be a limiting factor for infiltration reduction efforts, then it seems advisable to consider a grab sampling strategy. In general, more grab than integrated samples can be obtained within a given set of resource constraints, particularly at times when human resources are more available than funds for outside services. Perhaps more important, grab sampling offers the advantage of a quick turnaround time, which is important when sample placement is to be guided by previous sampling results.

The Maine and Houston grab sample data summarized in Table 1 may be compared with the composite living area integrated data shown in Fig. 2. The geometric means and standard deviations of the grab sample data determine theoretical distributions quite similar to the observed distributions seen in the probability plot. The degree of similarity between radon levels predicted by the two sampling methods is shown in Table 5, in which the living-area radon concentrations are shown at several percentiles of a log normal distribution. Distributions constructed from the integrated data were based on a 3–5 month record from each of three detectors in the living area of each house, while the grab sample distributions were based on a single instantaneous sample from some of the sites equipped with integrating detectors. Grab samples were not obtained from all of the sites visited, particularly in the Houston case. Nevertheless, in each geographic area the grab and integrated sample sets describe quite similar situations. If, for example, one were to assume a working level ratio of 0.5 and an indoor standard of 0.015 working levels, the radon concentration of interest would be 3 pCi/l. By either the grab or integrated sampling model, it is readily seen from Table 5 that less than 2% of the Houston area dwellings would be over that limit, whereas approximately one-quarter of the conventional dwellings in the central Maine study area would be considered to exceed the standard.

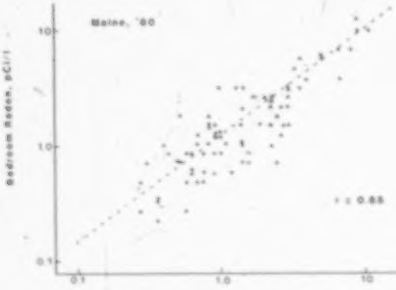

Fig. 3. Scatter diagram of integrated bedroom and integrated first-floor radon measurements made in dwellings in central Maine.

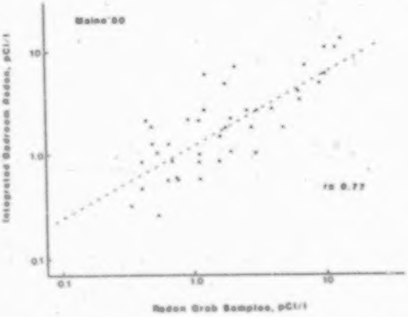

Fig. 4. Scatter diagram of integrated bedroom and grab sample radon measurements made in dwellings in central Maine.

Aside from considerations of the relative merits of grab and integrated sampling, there are a number of other features of the data that relate to radon survey design. The general agreement of the means of the living-area data in both Maine and Houston suggests that one detector per dwelling would be adequate for most purposes, providing that radon source areas are avoided. The Maine data strongly implicates the basement as a radon source, and, to a lesser extent, the bathroom. The high levels of radon in the Maine water supplies, together with the significantly elevated levels of radon in the bathrooms, demonstrate that the water supply can be an important factor affecting indoor radon concentrations. The slope obtained from the regression of the

Table 5. Indoor radon concentrations (pCi/l) at several percentiles as predicted by integrated and grab data.

Predictor	Samples	50%	75%	90%	98%
Houston integrated	303	0.47	0.74	1.1	1.8
Houston grab samples	23	0.49	0.85	1.4	2.6
Maine integrated	243	1.5	2.6	4.2	8.1
Maine grab samples	57	1.7	3.5	6.9	16.1

bedroom radon concentration on the concentration of radon in the water (c.f. Table 4) is 0.04 pCi/l (air) per nCi/l (water), in rough agreement with a ratio of 0.1 pCi/l (air) per nCi/l (water) projected for a theoretical dwelling (Gesell and Prichard, 1980). Although the value of r^2 obtained from this regression is modest, the link between radon in groundwater and radon in the dwelling is plausible, since elevated concentrations of radon in the soil gas could be expected to affect both the groundwater and structures built on the surface.

Conclusion

The data presented and referenced here demonstrate a pronounced trend toward log normality in indoor radon measurements taken in a given area. It was seen that logarithmic distributions estimated from grab sample data were similar to those estimated from more extensive 3-5 month integrated data in both the Maine and Houston study areas. The association between water grab samples and integrated indoor radon concentrations, while far weaker than that of the air grab samples, suggests that water sampling programs might also have some role in locating geographic areas in which there might be a potential for elevated indoor radon concentrations.

Acknowledgements – This work was supported in part by NIEHS Grant #5R23ES01742 and by NIH-BRSG Grant #S07R05828.

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Environment International, Vol. 8, pp. 59-66, 1982

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0160-4120/82/070059-08$03.00/0

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VARIATIONS OF AIRBORNE AND WATERBORNE Rn-222 IN HOUSES IN MAINE

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Concentrations of airborne radon ranging from 0.05 to 135 pCi/L were found in houses in Maine. Track-etch cups were placed in five positions for 100 houses to determine integrated average radon concentrations over the period October 1980–May 1981. To investigate the association between elevated radon concentrations in well water and the indoor airborne radon concentrations, the radon in the water supplies of these houses was measured by liquid scintillation. Monitors of airborne radon, recording in intervals of 10 min for periods of 5–7 days, were used for dynamic studies in 18 houses, determining the component of airborne radon associated with major water uses, such as showers, laundry, and dishwashing, which liberate radon in bursts. House residents kept logs noting the time of major water uses. For some of the houses, ventilation rates ranging from 0.3 to 2 air changes per hour were determined by analysis of the dynamic data. The component of airborne radon associated with water sources was found to vary inversely with ventilation rate and directly with waterborne radon concentration, with 0.8 ± 0.2 pCi Rn/L air per nCi Rn/L water at a ventilation rate of 1.0 air change per hour. The data are pertinent to a study which has revealed significant correlations between county averages, from the National Cancer Institute, or age-adjusted cancer mortality rates in Maine and average values of radon concentrations in water for the counties.

Introduction

Measurements of radon in the air of houses have been of interest in recent years due to the expectation of increased radiation doses to lungs as house ventilation rates are reduced for energy conservation. Radon in the air in uranium and other mines has been found to cause lung cancer, and, as a result, radon levels are presently controlled to below prescribed limits by forced ventilation of the mines with fresh air. Radon levels in the air in houses are generally much lower than levels which caused lung cancer in the poorly ventilated mines, but people spend much more time in houses and other buildings, perhaps as much as 90% of their lives. If an assumed linear relation between radiation dose and cancer risk is correct, then the low doses experienced by large populations from normal radon levels in the air in houses may produce significant numbers of lung cancers, though the individual risk is usually low compared to the previously uncontrolled uranium mine situations.

The current standard for uranium mines requires that annual exposures from radon daughters be below three working level months per year, corresponding to a 0.25 working level exposure rate for 12 months at 170 working hours per month. A person will receive an exposure of three working level months if he spends 18 h every day for a year in a house with air having 0.078 working levels of radon daughters. A few of the radon levels and corresponding working levels measured in houses in the present study are of this order, indicating that the risk of lung cancer from radon in some houses may be significant whether or not the linear dose-response hypothesis is correct.

The risk from radon and its daughters in houses has been estimated in a recent U.S. Environmental Protection Agency study (Guimond *et al.*, 1979). Using standard models for the linear extrapolation of dose rates and health effects from uranium mine conditions to household conditions, the lifetime risk from lifetime residence in housing having 0.02 working levels was estimated to be 1000 to 3000 lung cancer deaths per 100,000 persons.

Measurements of radon levels in the air of dwellings are underway in a number of countries. Reports of surveys of radon levels have been published for houses in England (Cliff, 1978), Norway (Stranden *et al.*, 1979), Sweden (Swedjemark, 1980), Hungary (Toth, 1972), Austria (Steinhousler *et al.*, 1978), and Poland

(Pensko, 1969). Radon and radon daughter measurements have also been reported for houses in Ontario (Taniguchi and Vasudev, 1980), (Dilworth, *et al.*, 1979), Saskatchewan (Keith, 1978), 13 major Canadian cities (McGregor, 1980), New Jersey and New York (George and Breslin 1979), New York (Fleischer *et al.*, 1981), California (Nazaroff, 1981), Illinois (Toohey, 1981), Florida (Guimond *et al.*, 1979), and Colordo (C. E. McGuire, Inc., 1979).

In some regions where radon levels in household air have been found to be high, due to enhancement of the radium in soil or building materials, usually from use of materials with high radium content brought to the surface in uranium or phosphate mining, criteria for radon levels in air above which remedial action is recommended have been established by governmental agencies. In Grand Junction, CO, where houses have been built on uranium mine tailings, the U.S. Surgeon General's guideline for remedial action is 0.05 working levels, with action suggested for levels between 0.01 and 0.05 working levels as well (U.S. Government, 1972). For houses built on inactive uranium processing sites, the U.S. Environmental Protection Agency recommendation calls for remedial action for houses with more than 3 pCi Rn/L air (USEPA, 1980). In Sweden, the criteria allow a maximum of 1.9 pCi/L for radon daughters in new dwellings, 5.4 pCi/L in rebuilt dwellings, and 10.8 pCi/L in existing dwellings (Åkerblom and Wilson, 1981). The high levels found in the air of some Swedish houses to which these criteria apply are due to natural radium content of soils and building materials, with no technological enhancement.

The state of Maine has significant fractions of its surface area covered with granites and other rocks bearing high radium concentrations. Granites in Maine have up to 25 ppm (μg/g) uranium, the ultimate progenitor of radon. Radon in water from 136 wells in granitic regions of Maine has been measured to average 22,000 pCi/L, with 13,600 pCi/L for 35 wells in sillimanite terrain, and 1100 pCi/L for 56 wells in chlorite grade terrains (Hess *et al.*, 1979). These conditions indicate a possibility for strong emanation of radon from the soil and rocks surrounding the foundations of houses, with consequent high inputs of radon through cracks or openings in foundations, and possibly high inputs of radon into houses with use of water from wells with high radon content. In addition, if construction materials are taken from local rock quarries, they may emanate radon directly into the household air from their radium content.

The concentration of radon in household air depends on the magnitude of each of these sources, the ventilation rate for mixing with outside air, and the radioactive decay rate for radon. The concentration of radon is determined by

$$dA/dT = R_{sg} + R_{bm} + R_w + R_o - (\lambda_v + \lambda_d)A,$$

where A is the pCi radon-222 per liter of house air, t is time, λ_d is the decay rate for radon 222, λ_v is the ventilation or air-change rate for the house, R_{sg} is the input of radon with soil gas, in pCi/L h, R_{bm} is the input for radon from building materials, R_w is the radon input from the water supply, and R_o is the input of radon with outside air. Any of the sources can be time dependent for a variety of reasons, for example, showering liberates a burst of radon during the short time it lasts, and changes in atmospheric pressure and humidity affect rates of soil gas penetration through foundations and outgassing of construction materials. Ventilation rates, λ_v, are normally greater than 0.1 air change per hour, while the decay rate for radon-222, with a 3.8-day half-life, is 0.0076/h, so λ_d is not significant in affecting indoor airborne radon concentrations. A solution for the equation, for the case where all sources are constant in time and are represented together as R, is

$$A = R/\lambda_v.$$

It can be seen that measurements of radon in air, A, will allow characterization of the sources of input, R, only if ventilation rates are determined along with the radon levels.

Methods

A set of 500 F-1 track etch cups (Fleischer *et al.*, 1980) was placed, 5 per house, in 100 houses in October 1980 and collected in May 1981 to determine integrated average radon levels during the cold season, when ventilation would be expected to be minimal for economy in heating. Of all the houses, 55 were located in geological regions in which high levels of radon in water are frequently found. For each house, cups were placed in a first-floor bedroom, first-floor bathroom, basement, living room, or kitchen, and shed or other well-ventilated place outside the living area.

At the same time the set of cups was placed, water samples were taken for determination of radon concentrations by the liquid scintillation method of Prichard and Gesell (1977).

The detectors (Wrenn *et al.*, 1975) used for the dynamic data on air radon concentrations collect daughters from the decay of radon which has diffused through a foam cover into a 1-L volume. An electrostatic field attracts positive ions onto a thin aluminized mylar film covering a ZnS(Ag) phosphor which is viewed by a photomultiplier tube. Alpha decays of radon daughters on the mylar film were counted for periods of 10–20 min; the sums were automatically printed on paper tape at the ends of the periods. The two detectors used were calibrated for radon sensitivity and humidity dependence by placing them in a sealed drum with a radium-226 standard solution. For one of these detectors, calibration was checked at radon facilities at New York University, at the Department of Energy Environmental Measurements Laboratory in New York City, at the University of Texas School of Public Health in Houston, and at the Eastern Environmental Measurements Laboratory in Montgomery, AL.

The 18 houses studied with Wrenn detectors were located between Orono and Bar Harbor, ME. For each house, a detector was placed in the living room or kitchen and left operating for 5–7 days, during which time the inhabitants were asked to keep a log, noting the times of major water uses such as showers, baths, dishwashing, and laundry washing.

For some of the houses, radon daughter working level measurements were made by the Kuznets method (Kuznets, 1956), which involves counting alpha decays of radon daughters gathered on membrane filters with an air sampling pump. In some instances of high radon concentrations, relative radon levels were determined with series of small air grab samples, using 24-cm^3 liquid scintillation vials coated on the inside with ZnS(Ag) powder over silicon grease. These grab samples, referred to as Z cells, were counted in a liquid scintillation machine, giving results useful for radon concentrations above 5 pCi/L air.

Results

Track etch cups

The results for radon concentration averages measured with track etch cups in the five different positions in the houses are shown in Fig. 1 as numbers of houses versus radon concentrations in 1 pCi/L increments. The number of cups collected, from which data was obtained, ranges from 68 to 85 for the five positions. The data for radon levels outdoors or in very drafty sheds has an arithmetic mean of 0.8 pCi/L. The averages for the other positions are 3.0 pCi/L in bedrooms, 3.4 pCi/L in bathrooms, 3.1 pCi/L in kitchens and livingrooms, and 6.4 pCi/L in basements. Deletion of the data for two houses with extraordinarily high overall radon levels reduces the average for each position by about 10%.

The average basement radon level is nearly twice as high as the averages in the other rooms. This indicates that radon entered the houses in the basements, possibly with soil gas diffusing through foundations or entering via drain pipes, or by emanation from basement water wells or basement building materials. Reduction of radon concentrations on the first floors may indicate that they have weaker radon sources or higher ventilation rates than the basements. A few track etch cups placed in second-floor bedrooms indicated that second-floor radon concentrations were lower than first-floor concentrations by roughly a factor of two.

To test the hypothesis that radon in water supplies is a source of airborne radon, radon in bathroom air, as measured in the track etch cup studies, is plotted versus radon in the corresponding water supplies in Fig. 2. The regression line shown for the data is significant, with $r = 0.307$, $n = 85$ measurements, slope = 0.107 pCi/L air per nCi/L water, and intercept at 1.6 pCi/L, indicating that water may be the source for some, but not all of the radon in the air. The results for radon in air in other positions in the houses show similar correla-

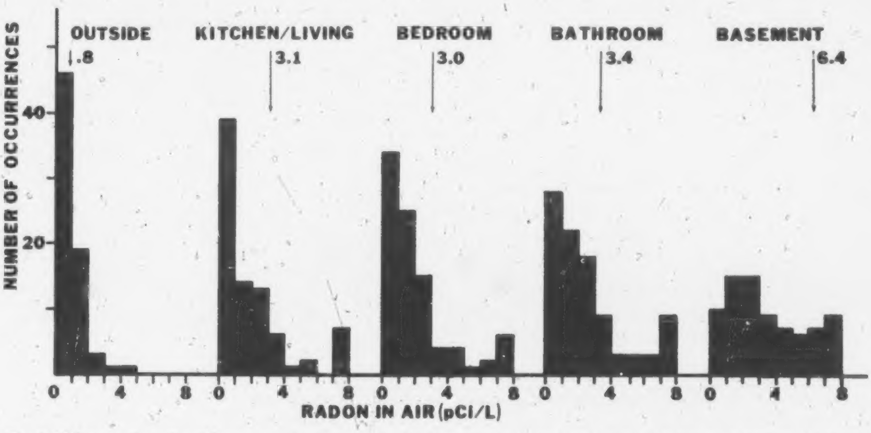

Fig. 1. Histogram of number of houses vs radon concentration in air measured with track etch cups in kitchens or livingrooms, bedrooms, bathrooms, basements, and outside. Occurrences of greater than 8 pCi/L are included in the eighth increment for each place.

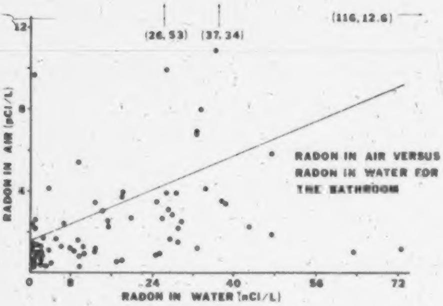

Fig. 2. Radon concentrations in bathroom air measured with track etch cups vs radon in water measured by the liquid scintillation method.

tions with water supply radon levels. Sources, such as soil gas, which contribute to the air radon levels recorded by the track etch method, are probably also correlated with radon in water.

Dynamic studies

Portions of the data from the continuously recording radon detectors are shown in Figs. 3–5. The times of various water usages are indicated and explained in the figures. Generally, a spike of radon shows up in the air shortly after a shower or the use of a washing machine or dishwasher, and sometimes a low spike can be seen after a bath was run. The times indicated for water uses are those given by the inhabitants of the houses, and are approximations of varying accuracy.

The data presented in Fig. 3 are for a typical house with a relatively low radon level in the water supply (6.5 nCi/L) and a low ventilation rate, while Fig. 4 shows data from a house with more radon in the water supply (18 nCi/L), a low ventilation rate, and a significant continuous background radon level on top of which the spikes from water use appear. Portions of data from two houses are presented in Fig. 5; those for house 7 (27 nCi/L) show little radon other than that associated with water use, and house 18 was exceptional in that it had the highest average radon in air, 87 pCi/L. For this tightly sealed solar house, the variations in the radon concentrations associated with showers or other water uses were not significant enough to show up against the high background. The source of the radon was an integral greenhouse; its strongly emanating floor was crushed gravel over granite bedrock, with no impermeable interface.

Table 1 presents a summary of the results for the 18 houses in which dynamic radon levels have been measured.

In determining the ventilation rates of the houses from the characteristics of the radon spikes associated

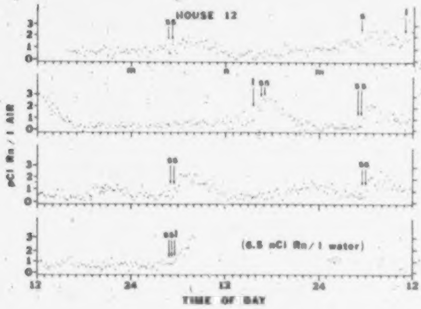

Fig. 3. Radon concentration in house 12 vs time of day for 7 days. Noon marked n. Showers are marked with letter s, and laundry with l.

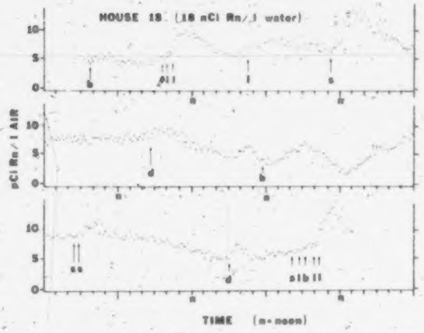

Fig. 4. Radon concentration in house 18 vs time of day for 7 days. Water uses marked as in Fig. 3, with b for bath and d for dishwasher use.

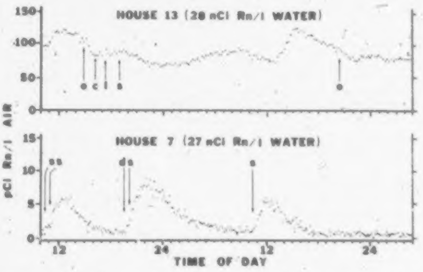

Fig. 5. Radon concentrations in houses 13 and 7 vs time of day. Water uses marked as in Fig. 3, with o for opening window and c for closing window.

Table 1. Summary of data for radon in 18 houses.

No.	Town	Date	Residents	Water Rn (pCi/L)	Mean Air Rn (pCi/L)	Rn Daughters Working Level	Air Rn from Water (pCi/L)	Ventilation Rate (Air Change/h)
1.	Orono	6/79	2	330	1.1	–	< 0.3	< 1.0
2.	Orono	7/79	3	330	0.6	–	0.3	–
3.	Orono	7/79	3	330	0.6	–	0.3	–
4.	Dedham	7/78	4	52,000	2.6	–	1.9	$2.0^{+1}_{-0.5}$
5.	Prospect	1/80	4	25,000	9.	0.03	–	–
6.	Orrington	2/80	3	17,000	3.0	–	1.7	0.5 ± 0.1
7.	Dedham	5/80	4	27,000	3.2	0.008	3.2	0.4 ± 0.1
8.	Dedham	5/80	2	22,000	2.0	–	< 1.5	–
9.	Dedham	5/80	4	25,000	2.0	–	< 1.5	–
10.	Mt. Desert	10/80	2	6,000	1.5	–	–	–
	Mt. Desert	7/80	2	7,000	0.25	–	–	–
11.	Dedham	10/80	2	8,000	5.2	–	< 1	–
12.	Dedham	10/80	2	6,500	1.5	–	0.7	0.5 ± 0.1
13.	Dedham	10/80	3	28,000	87	0.16	< 5	< 0.5
		10/80			201	0.26 (Greenhouse)		–
14.	Mt. Desert	10/80	2	20,000	3.0	–	–	–
15.	Mt. Desert	11/80	2	28,000	9	–	4.5	0.4 ± 0.1
16.	Dedham	11/80	4	31,000	35	0.075	–	–
		11/80			–	0.30 (Basement)		–
17.	Clifton	11/80	5	35,000	4.6	–	–	–
18.	Mt. Desert	11/80	5	19,000	8	–	3	0.3 ± 0.1

with water use, slowly falling spikes will be associated with low ventilation rates, and vice versa. In analyzing spikes, the characteristic response of the radon detector must be known. Figure 6 shows the response of a radon detector to a short burst of radon from a shower in a house with a very high ventilation rate (house 4, 2 air changes/h). In the same figure are plotted relative instantaneous radon levels, determined by grab samples with Z cells taken at the same location as the radon detector (in the living room). The response of the radon detector is delayed, because of the time for diffusion of the radon through the foam cover of the detector and the buildup time of the 3-min polonium-218 alpha activity. The delay time for transport of the radon from the shower to the vicinity of the detector in the living room can also be seen in this figure. The decrease of alpha activity on the detector is associated with the 20 and 27 min (half-life) beta activities, ^{214}Pb and ^{214}Bi, which delay the ^{214}Po alpha particles.

To determine ventilation rates from the data for the radon bursts, we have calculated solutions to the Bateman equations for the theoretical time dependence of the alpha-emitting radon daughter activities on the Wrenn detector scintillator. An exponentially decreasing radon concentration in the room due to ventilation is assumed. The delay for the diffusion of the radon through the foam cover of the detector has been treated as an additional first-order differential equation in these calculations, with λ (diffusion) determined, from detector response data such as in Fig. 6, to be 5/h. Theoretical detector response curves calculated in this manner for several ventilation rates are presented in Fig. 7. For high ventilation rates, the curves fall off at a rate determined chiefly by the 20 min ^{214}Pb and 27 min ^{214}Bi precursors of the 0.03 ms (half-life) ^{214}Po alpha emitter, the radon in the air around the detector having been eliminated by ventilation before the collected daughters decay. For low enough ventilation rates, the differing rates of decrease predicted for activity on the detector permit significant discrimination among the ventilation rates. Fits of some calculated curves to data for radon bursts are shown in Fig. 7. Those house ventilation rates which could be reliably determined from the dynamic data are given in the last column of Table 1.

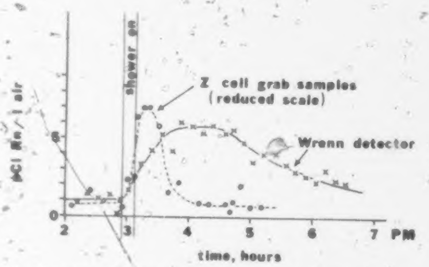

Fig. 6. Radon concentration after shower as measured in the living-room air with grab samples (Z cells) and a Wrenn electronic radon detector.

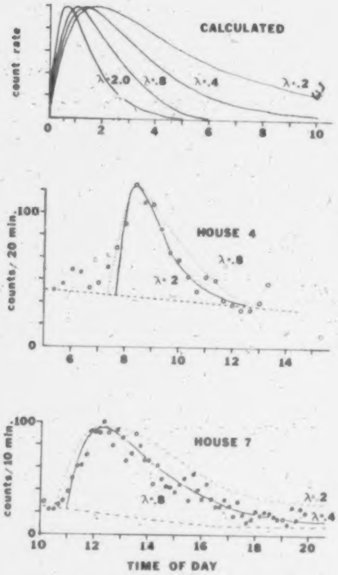

Fig. 7. Calculated theoretical responses of a Wrenn detector to exponentially decreasing radon concentrations as a function of ventilation rate, in air changes per hour, and fits of calculated curves to data for houses 4 and 7.

For most of the houses, the average concentration of radon in the air due to the water supply source can be determined from the data for the component of the radon appearing in jumps at times of water uses logged by residents. The averages of the components appearing in bursts at these times are given in the eighth column of Table 1. In addition to this component, there are continuous, slowly varying, and weak emissions of radon from water used in sinks, baths, and toilets.

The outgassing of radon from static water and small water uses cannot be distinguished from the continuous radon levels from other sources, so their contributions have been estimated indirectly. Radon emanation rates for static and agitated water in representative surface-to-volume geometries have been measured in the laboratory by monitoring the radon concentration in the water with the liquid scintillation method. The water radon concentration decreases exponentially at a constant rate which depends on the agitation. For water used in showers and dishwashers, the decrease in radon concentration has been directly determined by measuring the concentrations in the input and discharge water. The results for the loss of radon from water in various uses are presented in the third column of Table 2.

From the information summarized in Table 2, including statistics (Kreissl, 1978) for average per capita water consumption rates for various uses, the slowly and weakly emanating water sources for airborne radon (sinks, toilets, and baths) can be estimated to be about one-third as strong as the sources which liberate radon in large, observable bursts (showers, laundries, and dishwashers). Thus, the values in column eight of Table 2 for average levels of airborne radon liberated from water in observable bursts should be increased by about 33% to obtain the total average radon concentration in air due to radon in the water supply.

In Fig. 8, the levels of airborne radon from water, normalized for a water concentration of 10 nCi/L for each house, assuming direct dependence of airborne radon from water supplies on water radon concentrations, is plotted versus ventilation rate. The figure indicates that the air radon concentrations depend inversely on ventilation rates. After correcting this amount, because the total airborne radon from all water sources will be about 33% higher than the component appearing in bursts which is plotted in Fig. 8, there are seen to be 0.8 pCi Rn/L of air per 10 nCi Rn/L of water in a house with ventilation rate 1.0 air change/h.

Total radon concentrations in air for the 18 houses have been plotted as stars versus water radon concentrations in Fig. 9. Open circles in the figure are the average radon air concentrations due to water supply use and coming in noticeable bursts, these averages being normalized, according to an assumed inverse ventilation rate dependence, to those expected for a ventilation rate of one air change per hour. With a 33% increase for slowly and weakly emanating water sources of airborne

Table 2. Outgassing of radon from water use.

Water Use	Liters/ Person Day (Kreissl, 1978)	Fraction of Radon Lost	No. of Measurements This Study	pCi Rn Liberated (Person day pCi/L Water)
Dishwasher	19	0.98	1	18
Shower	20	0.65	4	13
Laundry	40	0.9 (estimated)	0	35
Sink	20	0.3 (estimated)	1	6
Bath	18	0.3 (estimated)	0	6
Toilet	35	0.3 (estimated)	0	12
				90 TOTAL

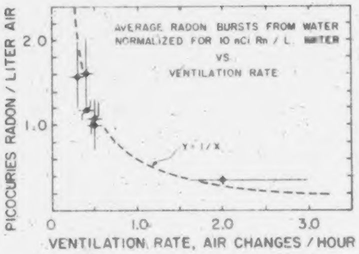

Fig. 8. Average radon in air from water use pulses, normalized to 10 nCi Rn/L of water, vs ventilation rate.

radon, the rate of air radon concentration dependence on water radon concentration is again 0.8 ± 0.2 pCi Rn/L of air per 10 nCi Rn/L of water.

The estimated exposures from airborne radon from all sources range from 0.01 to 14 working level months per year for the residents of these 18 houses when corrections are made for increased ventilation in the summer months.

Correlation

To investigate the significance of exposures to high levels of radon in water and corresponding high levels of radon in air, the correlation (Hess *et al.*, 1979) between age-adjusted cancer rates for the 16 counties in Maine (Mason, 1975) and county averages for radon concentrations in water, as estimated from more than 2000 water samples (Hess *et al.*, 1979) was calculated. The numbers of cases of lung cancer were 3682 for males and 656 for females from 1950 to 1969. The data for the correlation calculation are shown in Fig. 10. Age-adjusted lung cancer deaths per 100,000 person years for males and for females in each country are shown versus areally averaged water radon concentrations for the counties. The regression line for males has a slope of 6.0 cases per 100,000 person years per 10,000 pCi Rn/L of water and an intercept of 30 cases per 100,000 person years. The correlation coefficient *r* equals 0.46, with a 0.05 probability of being spurious. The regression line for females has a slope of 2.0 cases per 100,000 person years per 10,000 pCi Rn/L of water, and an intercept of 3.8 cases per 100,000 person years. For females, the correlation coefficient *r* equals 0.65, with less than 0.01 probability of being spurious. Significant correlations were also found for all cancers together versus county averages for radon in water. The methods used parallel those of Segal (1962), who studied background radiation in New England.

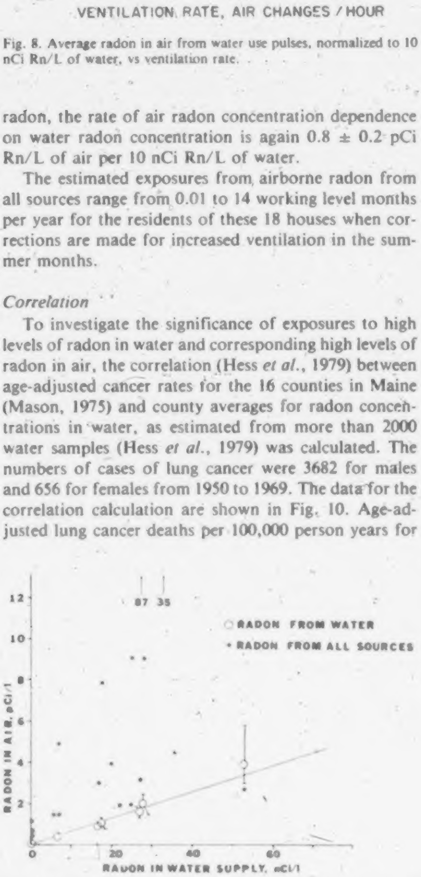

Fig. 9. Mean values of radon concentrations, air vs water, for 2-7 days during the heating season. The asterisks are for total radon observed, while the circles indicate average values due to water use pulses, normalized to 1 air change/h.

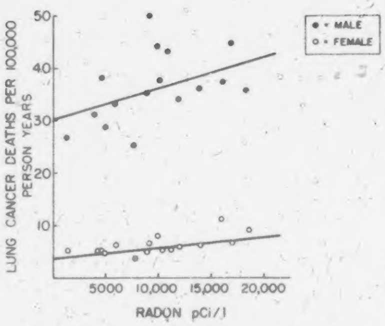

Fig. 10. Age adjusted lung cancer rates for males and females, in deaths per 100,000 persons per year, for 16 Maine counties, vs water radon concentrations for the counties.

Sources of airborne radon in houses other than water may be correlated with radon in water. Radon may diffuse from aquafer minerals into houses along with other soil gases, and locally obtained construction materials may have radon emissivities correlated with radon concentrations in well water.

Correlations of this sort cannot by themselves show causality. Among the causes of lung cancer are cigarette smoking and exposure to asbestos, as well as radiation exposure. A complete epidemiology study of lung cancer patients and their exposures to these agents is needed to show the magnitude of risk from each agent.

Conclusions

The average radon level measured with the track etch cups in the living areas of the houses was higher than 3 pCi/L air, which is the recommended criterion for remedial action for houses built on inactive uranium processing sites. The radon levels measured in air are significantly correlated with concentrations of radon in the water supplies for the houses, with a regression line suggesting about 1.07 pCi Rn/L of air per 10,000 pCi Rn/L of water.

Dynamic studies with continuously recording radon detectors show bursts of radon released into the air at times of showers and uses of dishwashers and laundry machines. Ventilation rates can be derived from this data, which permit the conclusion that the component of airborne radon from radon in the water supplies depends inversely on ventilation rate and direction on concentration in the water supply, with 0.8 ± 0.2 pCi Rn/L air per 10,000 pCi Rn/L water at a ventilation rate of 1.0 air change/h.

Estimates of average levels of radon in the water supplies of the 16 Maine counties, based on over 2000 measurements, are significantly correlated with lung cancer rates in the counties. Smoking, asbestos, and other kinds of air pollution are known to be significant contributors to lung cancer, and it may well be that the correlations are influenced by geographical patterns for such factors. Geographical data to remove the effects of these additional variables from the correlations are not available. Under these conditions the correlations should only be interpreted as suggesting an association, and conclusions cannot be drawn without additional epidemiology studies of more comprehensive design.

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Geologic and Hydrologic Factors Controlling Radon-222 in Ground Water in Maine

by Willem F. Brutsaert, Stephen A. Norton,
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Reprinted from the July-August 1981, Volume 19, Number 4 issue of *Ground Water*

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ABSTRACT

High Radon-222 (^{222}Rn) concentrations exist in ground water from most granitic rocks in Maine. Some values exceed the suggested limit of 500 pCi/l (E.P.A., 1976) by more than 100 times. Although high values ($\bar{x}$ = 22,100 pCi/l) are conclusively linked with the granites, high values are also present in ground water in metasedimentary rocks from sillimanite- ($\bar{x}$ = 13,630 pCi/l) and sillimanite-orthoclase zone metamorphic terrains. Metamorphic (anatectic) pegmatites with hydrothermally introduced uranium are thought to be the source of radon in high grade terrain. At lower grade (chlorite to staurolite), no relationship exists between ^{222}Rn content and metamorphic grade, although each rock formation has a somewhat characteristic ^{222}Rn range from ground water, ranges which overlap. Considerable local ^{222}Rn variations exist within the same rock body, reflecting local geologic and hydrologic conditions. Data on well depth, type of well, well yield, overburden type and thickness, and water chemistry show that ^{222}Rn may increase slightly with well depth up to 50 to 75 m and is essentially constant thereafter. Low yield wells, generally associated with areas of thin overburden, tend to have higher ^{222}Rn values than high yield wells, normally associated with thick sand and gravel overburdens. ^{222}Rn concentrations decrease with increasing sodium concentrations, suggesting that low ^{222}Rn wells are closely linked with surface waters. No other chemical parameter (Na, K, Ca, Mg, Fe, Mn, Zn, and Cu) correlates with ^{222}Rn content within a single rock unit.

INTRODUCTION

Today, more than 41 percent of Maine's population depends on ground water as a source of fresh water (Caswell, 1978). Drilled wells are being installed for private water supply at an ever increasing rate in rural Maine. Many of these wells are located in granites widely distributed in coastal and southern Maine, which are also the most populated areas. Granites are well known to contain 10 to 100 parts per million uranium. Consequently, the likelihood of the daughter ^{222}Rn occurring in significant amounts is great.

Pathways of ^{222}Rn from water into humans may be twofold. An inhalation exposure may result when ^{222}Rn partitions into air from the water supply (Gesell and Prichard, 1977; Castrén, 1977). Alternatively, ingested water containing ^{222}Rn and its daughters will provide a net dose of radiation to the stomach and intestines (Suomela and Kahlos, 1972).

Private well-water users are particularly impacted by ^{222}Rn and its radioactive daughters via these pathways of ^{222}Rn from water into humans. ^{222}Rn has a rather short half-life (3.82 days). Also, being a noble gas, it easily diffuses out of water when sprayed, e.g., in a shower. In a private water supply system, the time between pumping and consumption of water is well within the half-life of ^{222}Rn. This is usually not the case in public water supply systems. Moreover, in Maine, for practical reasons, drilled private wells are almost exclusively in bedrock. Wells developed for public water supply systems, which depend on a high sustained yield, are almost always in sand and gravel aquifers in hydraulic contact with lakes or rivers. Except in a few isolated instances (Hess, *et al.*, 1979), the sand and gravel aquifers overlying these granites produce ground water with low concentrations of ^{222}Rn.

Analysis of medical statistics revealed that, for some cancers, the nation's top ten percent cancer incidence occurs in southern Maine, largely coinciding with areas where highest ^{222}Rn concentrations were found. Cause and effect relationships in cancer research are hard to evaluate (Hess, *et al.*, 1979). Nevertheless, it is known that continued exposure to these radionuclides can be carcinogenic (Castrén, 1977). Consequently, a knowledge of the controlling factors on the distribution of ^{222}Rn is highly desirable.

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Discussion open until January 1, 1982.

PREVIOUS WORK ON RADON-222 AND RADIUM-226 IN GROUND WATER

The major emphasis for measurements of enhanced natural radiation due to radon has been in areas such as underground mining, strip mining, or wells for gas or water. Exposures to radon from uranium tailings (U.S.D.H.E.W., 1969; Gesell and Cook, 1975) and liquefied petroleum gas as well as reclaimed phosphate land, (U.S.E.P.A., 1975a, b; Gesell *et al.*, 1977) have been presented.

The effort to study ^{222}Rn and ^{226}Ra in potable water supplies began with measurements by Thompson (1902) when he discovered radon in the water supply at Cambridge University in England. Recent measurements of ^{222}Rn in ground water in the United States have shown values ranging up to 30,000 pCi/l excluding Maine and New Hampshire but ranging up to 300,000 pCi/l in granitic areas of Maine and New Hampshire (Duncan *et al.*, 1976; Hess *et al.*, 1978).

Other areas of the United States with high values of radon in water supplies include North Carolina (Aldrich *et al.*, 1975), western United States (O'Connell and Kaufmann, 1976), Hot Springs, Arkansas (Kuroda *et al.*, 1954), Great Salt Lake, Utah (Tanner, 1963), and south Texas (Gesell and Cook, 1975).

Research on radon in ground water in Maine and New Hampshire has been done by Grune *et al.* (1960), Smith *et al.* (1961), Hoxie and Church (1966), Hoxie (1966), Lowder *et al.* (1963), Richardson (1964), and Hess *et al.* (1978). The values are highest in granitic areas and in areas which have large amounts of pegmatite (corresponding to high grade metamorphic terrain).

DISTRIBUTION OF ^{222}RN IN GROUND WATER

The concentration of ^{222}Rn in ground water depends largely on the concentration of its parent, ^{226}Ra, in the underlying rock. The short half-life of ^{222}Rn (3.82 days) (Figure 1) together with the slow migration of ground water allows the ^{222}Rn in solution to be in approximate secular equilibrium with the ^{226}Ra in the local rock. Radon concentration in water has been known to be high in most granites and in high grade metamorphic rocks whereas less metamorphosed rocks have somewhat less ^{222}Rn (Curi, 1910). The metamorphic zones for Maine are shown in Figure 2 (after Doyle, 1967). The highest ^{222}Ra-^{222}Rn levels in ground water are found in granites, sillimanite- or sillimanite/orthoclase-grade rocks; lower levels are found in chlorite- to staurolite-grade rocks, with no consistent relationships between the subsillimanite metamorphic grade and ^{222}Rn content within a single rock formation. Considerable local variations are present within the same rock body, however, reflecting local geologic and hydrologic conditions.

METHODS

To delineate geological areas with high ^{222}Rn in potable water supplies, private wells in Aroostook, Cumberland, Hancock, Lincoln, Penobscot, Waldo, Washington, and York Counties of Maine were sampled with special emphasis on granite and pegmatitic areas. Areas of known high cancer rate were also tested, for example, Cumberland County, Maine (Hess *et al.*, 1979). The sampling grid was formed with the advice of the State of Maine Department of Human Services, Health Engineering Division in Augusta, Maine.

The method for field sampling from wells for ^{222}Rn involved a procedure which was adopted from Gesell (personal communications, 1977) (Table 1). Running the water for 10 minutes avoided the measurement of old water held in the tank and well casing which had lost ^{222}Rn by decay or outgassing. A water sample of 100 ml was collected for chemical analysis to determine what elements are associated with the ^{222}Rn and to help characterize the bedrock aquifer. The use of

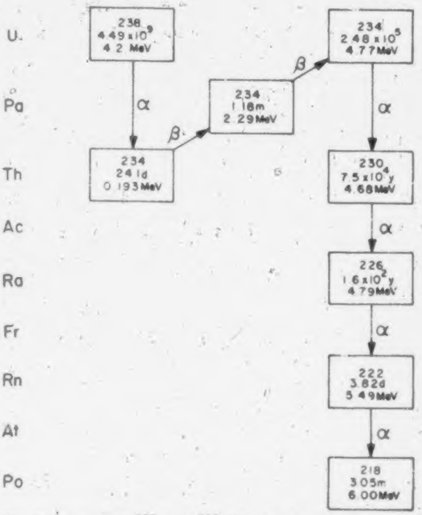

Fig. 1 Decay for U^{238} to Po^{218}. Within each block are atomic weight, half life, and energy of the decay.

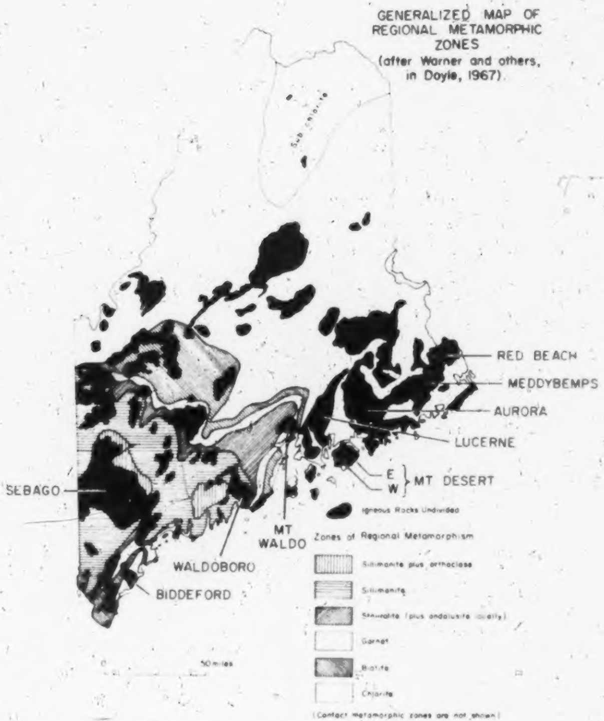
GENERALIZED MAP OF REGIONAL METAMORPHIC ZONES
(after Warner and others, in Doyle, 1967)
RED BEACH
MEDDYBEMPS
AURORA
LUCERNE
E
W
MT DESERT
SEBAGO
MT WALDO
WALDOBORO
BIDDEFORD
Igneous Rocks Undivided
Zones of Regional Metamorphism
Sillimanite plus orthoclase
Sillimanite
Staurolite (plus andalusite locally)
Garnet
Biotite
Chlorite
(Contact metamorphic zones are not shown)
0
50 miles

Fig. 2. Generalized geologic map of Maine showing metamorphic zones and granites.

the funnel and syringe prevents loss of ^{222}Rn into air and entrainment of air bubbles. The liquid scintillation vials were capped tightly to prevent loss of ^{222}Rn.

Table 1 also lists the counting procedure following the methods of Gesell and Prichard (1977). Standards of ^{226}Ra (SRM-4950-C) from the National Bureau of Standards were used for calibration. The fluor (Table 1) had no emulsifier so that the water and toluene separated after shaking into two transparent phases. The ^{222}Rn partitions in water, air, and toluene at 20° C as 1:3.92:49.8; therefore, about 86% of the ^{222}Rn initially in the water was in the toluene whereas 11.9% was in the air. This provided a count rate of 9.75 CPM/pCi ± 2 percent (Gesell and Prichard, 1977).

Water samples for chemical analysis were collected at each of the sites of Table 2 as well as about 300 nongranitic wells. Samples were collected in acid-washed (0.1 N Hcl) 120 ml polypropylene bottles which contained 5 ml of 50:50 HCl to preserve dissolved reduced species in solution. This technique has the disadvantage of causing the solution of any particulate colloidal Fe and Mn species as well as partial solution of suspended alumino-silicate minerals, releasing various alkalies and alkaline earths (K, Na, Ca, Mg, . . .). However, it is our experience that, except for newly drilled wells, particulate matter is not abundant in the water and our techniques yielded the most representative values for dissolved materials, particularly those materials whose solubility is influenced by oxygen levels.

All analyses were performed by flame atomic adsorption spectrophotometry on a Perkin-Elmer 303 (all elements except Mg) or on a Perkin-Elmer 703 (Mg). Methods used were those in the Perkin-Elmer methods manual.

Table 1. Methods for Sampling Wells and Counting Samples

Method for Sampling Wells for ^{222}Rn

1. Obtain information on well type, depth, rock type, and overburden.
2. Connect hose and funnel to faucet for sampling.
3. Run water for 10 minutes or until temperature of water is about ° to 11°C.
4. Take a 100 ml sample of water for chemical analysis.
5. Remove 10 ml of water from the funnel with a 15 ml syringe.
6. Inject the 10 ml of water below the scintillation fluor (5 ml) in the vial.
7. Cap vial and shake.
8. Record time and date of collection.

Method for Counting Samples

1. Packard Model 2450 liquid scintillation counter.
2. Counter is linked to a teletype.
3. Sample vials are standard liquid scintillation vials.
    - a. 20 ml glass vials with polyethylene caps (New England Nuclear).
    - b. Vials are loaded with 5 ml of scintillation fluor (New England Nuclear Liquifluor) prior to sample collection. Liquifluor is composed of 100 G of PPO and 1.25 G of POPOP in a concentration toluene solution.
    - c. Scintillation fluor must be diluted by adding 40 ml Liquifluor to one liter of liquid scintillation grade toluene.
4. Adjustable discriminates are set to obtain the greatest number of α- and β-counts from ^{222}Rn.
5. Each sample is placed in the scintillation counter and counted for 40 minutes.

Table 2. Summary of Radon Values for Ground Water from Various Granites in Maine

	# Wells	$\overline{\text{Radon}}$ (pCi/l × 10^3)	S.D.	# Wells of Known Depth	$\overline{\text{Depth}}$ (ft)	S.D.	# Wells of Known Yield	$\overline{\text{Yield}}$ (gpm)	S.D.
Sebago Granite	34	17.7	31.5	23	205	152	13	12.0	9.9
Lucerne Granite	27	35.8	27.4	24	199	134	9	15.5	18.6
Waldoboro Granite	22	19.6	18.3	18	146	96	6	13.7	10.8
Aurora Granite	12	13.8	10.4	10	141	80	5	24.3	33.2
Mt. Waldo Granite	10	31.0	25.0	8	152	78	2	7.5	3.5
Mt. Desert (W) Granite	9	15.5	8.8	6	146	78	2	53.5	65.8
Mt. Desert (E) Granite	6	3.0	2.2	9	98	45	3	6.2	3.4
Red Beach Granite	6	21.8	16.7	4	95	35	3	14.3	15.5
Meddybemps Granite	6	39.7	58.7	6	150	72	5	14.0	11.1
Biddeford Granite	4	1.5	0.7	3	92	52	2	32.5	38.9
	Σ = 136								

	N	$^{222}\overline{Rn}$
Well Depth		
0-100 ft	41	14.9
101-200	44	24.3
201-400	20	23.8
401+	6	36.3
Unknown	25	23.8
	Σ = 136	

	N	$^{222}\overline{Rn}$
Overburden:		
0-10 ft	25	27.3
11-50	25	19.6
51+	19	13.6
Unknown	67	23.0
	Σ = 136	

	N	$^{222}\overline{Rn}$
Overburden:		
Till	73	24.5
Sand/Gravel	36	9.8
Clay	7	17.6
Unknown	20	35.4
	Σ = 136	

	N	$^{222}\overline{Rn}$
Yield:		
0-4 gpm	12	38.3
5-10	18	21.7
11-25	12	15.0
26-50	4	8.7
51+	4	2.0
Unknown	86	22.1
	Σ = 136	

Precision for measurements varies according to the element measured and the absolute levels present. The following errors are associated with our reported values; Na ± 0.05 ppm (parts per million); K ± 0.05 ppm, Ca ± 0.05 ppm; Mg ± 0.02 ppm; Mn ± 0.1 ppm; Cu ± 0.05 ppm; Zn ± 0.01 ppm.

Ca was measured but the measurements were performed without the necessary compensation for dissolved Si, Al, and P. Consequently all the values are approximately 10% too high. Nonetheless the data were analyzed from a trend point of view and some are included in Tables 3-6. The type of information they yield is parallel to that for Mg.

Fe in ground-water samples was measured in the first part of our studies of ^{222}Rn in Maine ground waters. Most ground waters yielded Fe values of 0.1 ppm or less with perhaps 1 well in 15 reaching 1 ppm. High Fe was almost invariably linked to the bedrock chemistry and the presence of iron sulfides. Whereas high ^{222}Rn is linked with granites and very high grade metamorphic rocks and they characteristically have low or no sulfide content, we decided that little or no useful information would be revealed by Fe analysis that was not already explicit from Mn analysis.

RESULTS

The data analyzed in this study were collected during the Summer of 1977 and 1978 and published in part by Hess *et al.*, 1978, and Hess *et al.*, 1979. Data include ^{222}Rn concentrations, county, town, type of well, depth and yield of well, type of bedrock, type and thickness of overburden, and standard water chemistry.

Table 3. Chemistry of Water from Drilled Wells in the Vassalboro Formation (values are in parts per million)

Well #	*Depth (ft)*	*Na*	*K*	*Ca*[a]	*Mn*	*Mg*	*Cu*	*Zn*	*Radon (pCi/l)*
1534	70	10.5	0.72	46.5	t	4.85	*	0.02	1,626
1532	60	5.6	0.95	36.5	t	7.14	0.18	0.93	1,570
1530	110	5.6	1.15	40	t	10.58	*	0.04	3,986
1528	60	2.78	1.25	20.5	t	1.7	*	*	7,947
1526	27	n.d.	3.7	52	t	7.25	*	*	1,246
1518	110	10.0	7.7	46.5	t	6.75	0.09	*	1,771
1524	100	3.1	5.55	17.7	t	1.85	0.39	0.14	4,386
1522	200	20.0	2.38	n.d.	t	5.9		*	2,695
1520	375	16.5	2.6	20.5	t	7.1	*	*	3,614
1516	?	12.8	4.24	36.5	0.125	8.5	*	0.03	4,806

a Values are approximately 10% too high.
t Present at about level of detection (Mn, 0.1 ppm; Cu, 0.05 ppm, Zn, 0.01 ppm).
* Below detection limit (same as above).
n.d. Not determined.
(Wells are arranged in order of increasing metamorphic grade from biotite (#1534) to cordierite (#1516).)

Table 4. Chemistry of Water from Drilled Wells in the Waterville Formation (values are in parts per million)

Well #	*Depth (ft)*	*Na*	*K*	*Ca*[a]	*Mn*	*Mg*	*Cu*	*Zn*	*Radon (pCi/l)*
1492	?	n.d.	2.85	3.1	t	0.95	*	*	4,832
1494	?	4.8	2.55	90	t	4.95	*	0.20	389
1498	120	7.8	3.1	41	0.125	6.0	*	*	987
1496	?	35.5	2.52	60	t	4.5	*	0.45	761
1502	100	4.0	2.15	24.5	t	1.43	*	*	1,138
1504	?	6.6	3.9	41	t	5.1	*	*	2,432
1500	?	6.0	1.8	23.5	t	2.49	*	0.52	2,126
1510	?	n.d.	2.55	42.5	t	2.9	*	*	736
1506	58	3.4	1.14	14.2	t	1.1	*	0.03	1,652
1508	200	n.d.	3.00	5.8	t	1.54	*	*	1,582

a Values are approximately 10% too high.
t Present at about level of detection (Mn, 0.1 ppm; Cu, 0.05 ppm; Zn, 0.01 ppm).
* Below detection limit (same as above).
n.d. Not determined.
(Wells are arranged in order of increasing metamorphic grade from biotite (#1492) to cordierite (#1516).)

Table 5. Chemistry of Water from Drilled Wells in the Appleton Formation (values are in parts per million)

Well #	*Depth* (*ft*)	*Na*	*K*	*Ca*^{a}	*Mn*	*Mg*	*Cu*	*Zn*	*Radon* (*pCi/l*)
1295	122	11.0	2.0	26	0.120	7.8	•	•	2,929
1297	186	8.4	1.5	16.5	0.175	4.07	•	•	338
1299	250	8.0	2.7	15	0.20	2.8	•	•	2,118
1305	202	9.2	2.1	19.5	t	3.63	•	•	1,985
1309	173	5.8	1.05	5	t	1.9	•	•	1,674
1311	110	7.5	2.6	13.5	t	2.95	0.45	0.02	2,003
1323	86	2.9	2.05	3.8	t	0.91	•	•	1,693
1321	150	9.2	2.5	14.6	t	3.52	•	•	2,537
1319	185	14.5	2.4	11.4	0.075	2.2	•	•	735
1315	20?	22.0	2.6	12.6	0.15	3.31	•	•	1,286

a Values are approximately 10% too high

t Present at about level of detection (Mn, 0.1 ppm; Cu, 0.05 ppm; Zn, 0.01 ppm)

• Below detection limit (same as above)

n.d. Not determined

(Wells are arranged in order of increasing metamorphic grade from biotite (#1492) to cordierite (#1516).)

Geology

Histograms of ^{222}Rn concentrations in potable water versus rock type and metamorphic grade are given in Figure 3. The average value for ^{222}Rn concentration (pCi/l) for all granite terrains is 22.1 $\times 10^3 \pm 27 \times 10^3$; for sillimanite-grade $13.6 \times 10^3 \pm 13.8 \times 10^3$; and for chlorite-grade $1.1 \times 10^3 \pm 0.6 \times 10^3$. These ranges are estimates of one standard deviation assuming normally distributed data, where in fact these data are log-normally

Table 6. Chemistry of Water from Drilled Wells in the Lucerne Granite (values are in parts per million)

Well #	*Depth* (*ft*)	*Na*	*K*	*Ca*^{a}	*Mn*	*Mg*	*Cu*	*Zn*	*Radon* (*pCi/l*)
428	?	8.93	1.37	32.13	•	5.90	n.d.	n.d.	122,000
471	160	8.2	1.38	51.5	t	7.62	0.12	n.d.	77,000
432	170	n.d.	n.d.	n.d.	n.d.	21.38	n.d.	n.d.	69,000
416	175	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	64,000
467	200	11.00	1.38	51.5	t	7.42	0.10	n.d.	55,100
479	?	7.3	1.2	20.7	t	3.81	0.28	0.20	55,100
1357	130	11.2	1.55	23.5	0.15	5.97	n.d.	0.06	54,600
477	75	14.0	0.88	18.3	t	4.41	0.25	0.02	51,000
1009	400	6.5	0.38	25.0	t	0.81	0.15	n.d.	50,000
473	85	5.8	1.0	22.5	t	4.31	0.12	0.02	40,500
434	206	n.d.	n.d.	n.d.	•	16.11	n.d.	n.d.	38,000
442	235	5.32	0.64	15.89	•	2.08	n.d.	n.d.	36,000
420	160	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	29,300
465	70	1.65	0.37	n.d.	n.d.	0.32	n.d.	n.d.	27,400
469	50	48.0	1.55	4.90	t	0.86	0.15	3.1	21,300
1017	75	6.5	2.95	13.2	t	n.d.	0.10	0.05	19,300
1019	200	n.d.	n.d.	n.d.	t	n.d.	n.d.	n.d.	18,700
1015	425	4.6	1.45	24.6	t	n.d.	0.10	n.d.	18,500
446	?	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	15,500
1005	130	4.3	1.82	6.8	t	1.26	0.10	n.d.	13,700
438	145	5.20	0.94	13.89	•	2.64	n.d.	n.d.	13,500
444	475	14.33	0.58	32.75	•	1.85	n.d.	n.d.	12,500
1355	96	23.0	1.2	26.5	0.08	5.17	n.d.	0.14	3,900
1353	195	14.9	2.1	17.4	t	6.52	n.d.	n.d.	600

a Values are approximately 10% too high

t Present at about level of detection (Mn, 0.1 ppm; Cu, 0.05 ppm; Zn, 0.01 ppm).

• Below detection limit (same as above).

n.d. Not determined.

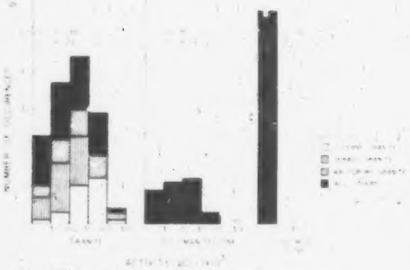

Fig. 3. ^{222}Rn activity as a function of rock type.

distributed. Considerable variation exists between granites (Table 2). Values obtained by Smith *et al* (1961) are generally lower than, but show the same trend as, the values of this study increasing ^{222}Rn concentration for granite ($20.6 \times 10^3 \pm 40 \times 10^3$) to sillimanite-orthoclase ($8.8 \times 10^3 \pm 28 \times 10^3$) to sillimanite ($8.6 \times 10^3 \pm 18 \times 10^3$).

Only the populated areas of Maine have been sampled. In this region, the structural trend of metasedimentary rocks is northeasterly whereas the metamorphic isograds (Figure 2) trend generally northwesterly. This enables us to sample the same rock units at different metamorphic grade. Figure 3 illustrates the general conclusion that chloride grade metasedimentary rocks (and on up to staurolite grade) have low ^{222}Rn values which are characteristic of the rock, not the metamorphic grade. Specifically, four different stratigraphic units were studied where they crossed from the biotite to the sillimanite zone. No trend was observed for calcareous (Table 3), pelitic (Table 4), quartzitic, calcareous graywacke, and turbidite (Table 5) stratigraphic units. Stratigraphic units did have characteristic but overlapping ranges of ^{222}Rn values. However, at sillimanite grade and above, metasedimentary rocks yield higher ^{222}Rn than their lower grade equivalents. This change coincides with the development of pegmatites within the rocks and presumably uranium mineralization. The ultimate sources of the uranium are probably the intrusive igneous rocks, primarily granites.

Hydrology

Well depth, overburden thickness and type, and well yield all seemed to affect variations in ^{222}Rn. An analysis of these relationships must be restricted to one rock type because of the heterogeneity of ^{222}Rn values from rock type to rock type. Additionally, it is desirable to restrict this type of analysis to one body of the same type of rock. For instance, in Figure 4 we depict ^{222}Rn versus well depth for 10 different (differentiated on Figure 2) granite bodies. It is difficult to infer any relationship. Therefore, for these 10 granites we have evaluated the relationship for well depth, overburden thickness, yield, and overburden type versus the mean deviation ($\bar{D}$) from the local rock type mean ($^{222}\overline{Rn}$), expressed in percent. The latter is defined as (Korn, G. and Korn, T., 1968)

$$D = \sum_{1}^{i} \frac{\overline{Rn}(int)_i - \overline{Rn}(area)_i}{\overline{Rn}(area)_i} \cdot \frac{n_i}{N} \cdot 100$$

where

$\overline{Rn}(int)_i$ = average ^{222}Rn concentration in a class interval (e.g., 0-100 feet deep wells) in a particular granite,

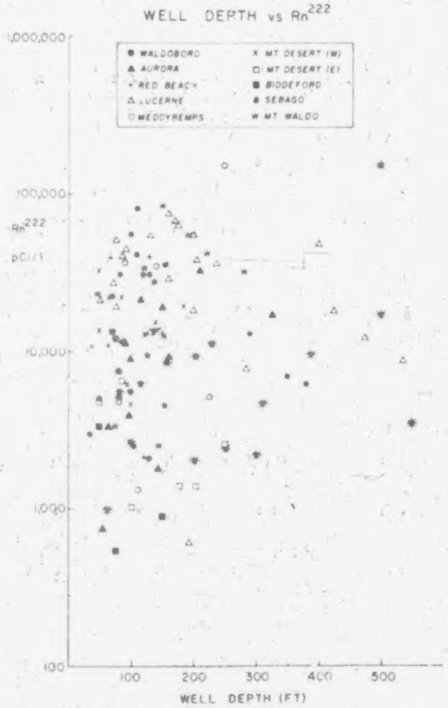

Fig. 4. ^{222}Rn activity as a function of well depth for granite.

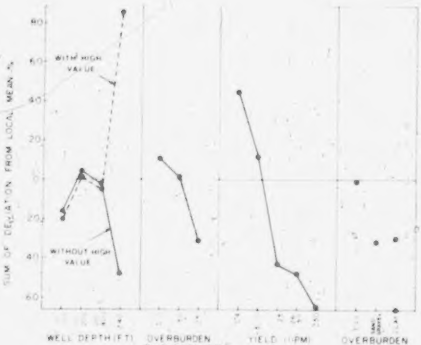

Fig. 5. Mean deviations of local ^{222}Rn values versus well depth, overburden thickness, yield, overburden type for Maine granites.

$Rn(area)_i$ = average ^{222}Rn concentration in all classes for the particular granite,

i = number of different granites = 10,

n = number of samples in a class in a particular granite, and

N = number of samples in a class in all granites.

Data represented this way are normalized with respect to the local mean, therefore accounting for its variability. The factor n_i/N or relative frequency, is a weighting factor for variable sample size within a class interval of the different granites. The data are tabulated in Table 2 and the results are shown in Figure 5. One very high ^{222}Rn value in the class ≥400 feet appears to affect the relationship of $\bar{D}$ versus well depth, because of the small n of this class. When this value is included, the relationship in Figure 5 is indicated by the dashed line, and may not be meaningful. When not included, the relationship appears to agree with data from previous studies (Grune *et al.*, 1960). Various factors may have an effect on this relationship, such as surface area of fractures, residence time of water flowing through these fractures, and residence time of water in the well bore. The variation of ^{222}Rn concentration in all granitic terrain wells is controlled by initial ^{226}Ra content on a very local scale. Assuming a rock porosity of less than 1%, perhaps as small as 0.01%, an effective rock formation thickness of about 20 to 30 m (dictated by a rapid decrease of water yielding fractures with depth), and a mean life of ^{222}Rn of 5.5 days, the concentration of ^{226}Ra in the rock (or dissolved in the water) within a 35 m radius of a well pumped for domestic usage must control the amount of ^{222}Rn in the water supply. Because the well receives most of its ^{222}Rn from nearby rock, the radioactivity tends to level off for wells around 50 m deep. The tendency of decreasing ^{222}Rn levels with increasing depth beyond 50 m may be due to increased residence time of water in the well bore, keeping in mind that this study deals only with domestic wells.

The decrease in $\bar{D}$ with overburden thickness is attributed to localized recharge of wells due to a thick porous saturated zone in the vicinity of the well. The decrease in $\bar{D}$ with increasing yield suggests that as rock fractures increase in transmissivity (increasing yield), rock-water interface area doesn't increase proportionally and thus ^{222}Rn concentration decreases in proportion to the volume of water.

Chemistry of Ground Water and Possible Linkage with ^{222}Rn Values

Preliminary studies of ground-water chemistry and ^{222}Rn indicated that it might be possible to determine relative age of ground water by the degree to which ground water had equilibrated with the bedrock during chemical weathering. The heterogeneity of the ^{222}Rn values in ground water from the same rock unit, but in different wells might be caused, in part, by the residence time of the water in the ground. For example, ^{222}Rn values in the Lucerne Granite range over a factor of 10 and perhaps the ground-water chemistry varied consistently with it. Alternatively, the distribution of radioactivity may be heterogeneous. Clearly, because of the half life of ^{222}Rn (3.8 days) and the rate of movement of ground water (0-10 meters/day), the heterogeneity for ^{226}Ra distribution (the parent) must, if present, be on a small scale.

The variability in the composition of precipitation is small over the regional extent of individual rock units (particularly granites). Thus, variation in ground-water chemistry must be caused by factors such as bedrock geology, extent of equilibration of ground water with the soils and bedrock and anthropogenic effects. Data collected within four discrete rock units are tabulated in Tables 3-6. The sites were selected to span the full range of metamorphic grade (Tables 3, 4, and 5) (Figure 2) in the area of outcrop. There is no relationship between ^{222}Rn levels and metamorphic grade (up to staurolite/andalusite) in rock units. Additionally, there is no relationship between ^{222}Rn levels and most dissolved constituents (see Figures 6, 9, 10, 11). However, Na appears to have a weak inverse relationship with respect to ^{222}Rn. This relationship is particularly clear for the Appleton Formation (Figure 7) data ($r = -0.53$) and less so for the Lucerne Granite (Figure 8) ($r = -0.28$). The relationship between low ^{222}Rn content and high Na values suggests a hydrologic linkage (local shallow recharge) between the well and either road salt or septic system contamination. This data set demonstrates the extent of contamination of private wells. Any well located in granite and not tapping trapped sea water (Caswell, 1978) should have Na levels below 10 ppm and probably below 5 to 6 ppm. Comparison of the Na vs. ^{222}Rn graph with the Mg vs. ^{222}Rn and K vs. ^{222}Rn graphs for the Lucerne Granite demonstrates the general lack of relationship between the extent of chemical

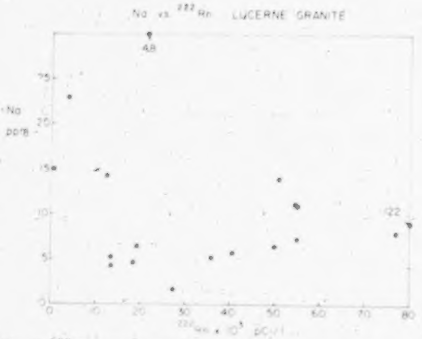

Fig. 8. ^{222}Rn concentration versus Na concentration—Lucerne Granite.

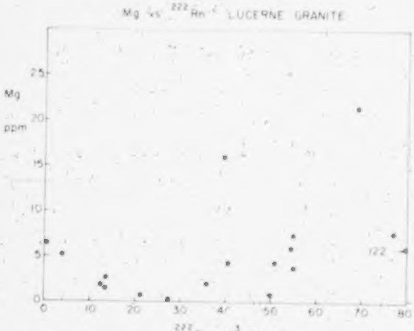

Fig. 6. ^{222}Rn concentration versus Mg concentration—Lucerne Granite.

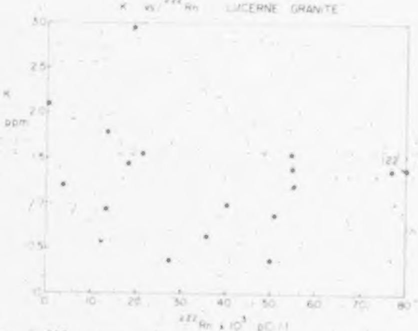

Fig. 9. ^{222}Rn concentration versus K concentration—Lucerne Granite.

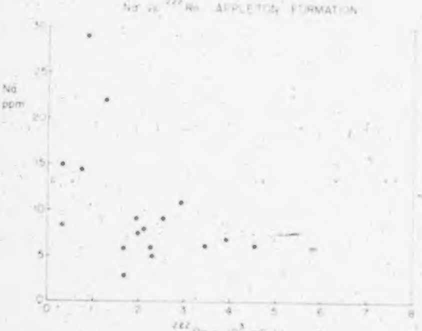

Fig. 7. ^{222}Rn concentration versus Na concentration—Appleton Formation.

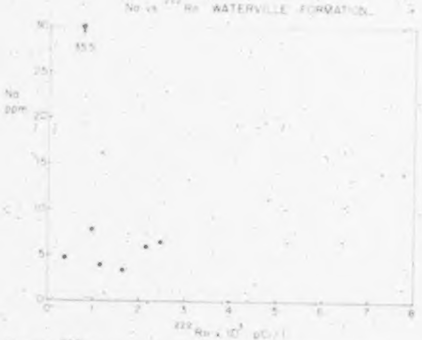

Fig. 10. ^{222}Rn concentration versus Na concentration—Waterville Formation.

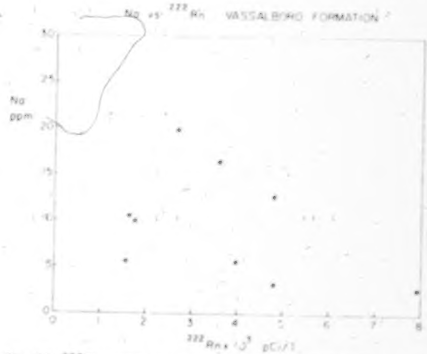

Fig. 11. ^{222}Rn concentration versus Na concentration—Vassalboro Formation.

weathering by ground water and the ^{222}Rn levels, except for Na. K is generally between 0.1 and 0.5 ppm in precipitation and for the sample set in Figure 9 could be assumed to be a constant value. The variation in total K is a function of extent of equilibration with the bedrock but it is not related to ^{222}Rn levels. A similar argument can be made for Mg (Figure 6).

The Ca and Mg concentrations for many wells are higher than would be predicted from considerations of precipitation chemistry and interactions with the bedrock. Ca concentration in ground water in a granitic terrain should fall in the 1 to 5 ppm range, considering both precipitation chemistry and reaction of the ground water with the bedrock. Less than one-fourth of the Ca values in the Lucerne Granite wells are in that range. Mg values for the Lucerne Granite (Table 6) and the other three rock units (Tables 3, 4, and 5) indicate that Mg levels are unexpectedly high (> 5 ppm) in a few wells. We interpret the high values as caused by local application of soil conditioners [$CaCO_3$ and $CaMg(CO_3)_2$].

Cu and Zn data show no meaningful relationship, either within individual rock units (Tables 3 to 6) or overall.

SUMMARY

^{222}Rn values relate to bedrock geology, hydrology, and ground-water chemistry as follows:

1. Granites have ground water with the highest ^{222}Rn values (generally 5,000 to 100,000 pCi/l). Within—and between—granite variation is large.

2. High grade metamorphic terrains (sillimanite and sillimanite plus orthoclase grade) have ^{222}Rn values in the range of 5,000 to 30,000 pCi/l. These values are believed to result from the development of metamorphic pegmatites with associated uranium mineralization.

3. Metasedimentary rock units at grades less than sillimanite have ground water with ^{222}Rn levels in the range of 1,000 to 10,000 pCi/l. Each rock unit has a somewhat characteristic ^{222}Rn range for ground water, ranges which overlap.

4. ^{222}Rn values within granites increase with depth and plateau at about 100 feet.

5. ^{222}Rn values for granites vary inversely with well yield.

6. ^{222}Rn values do not relate strongly to levels of dissolved K, Mg, Ca, Zn, Cu, or Fe.

7. ^{222}Rn values are weakly inversely related to Na values.

8. Na, Ca, and Mg levels in some private wells are strongly influenced by anthropogenic effects, including road salt and soil conditioners.

ACKNOWLEDGMENTS

The work upon which this publication is based was supported in part by funds provided by the Office of Water Research and Technology (Project No. A-045), U.S. Department of the Interior, Washington, D.C., as authorized by the Water Research and Development Act of 1978 and in part with funds from the U.S. Environmental Protection Agency under grant No. F-001-157-780. Additional funds and cooperation provided by the Maine Department of Human Services, Health Engineering Division, are gratefully acknowledged.

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* * * *

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Stephen A. Norton, Chairman of the Department of Geological Sciences at the University of Maine at Orono, received the A.B. degree in Geology from Princeton University and M.A. and Ph.D. in Geology from Harvard University. For the period 1962 to about 1970 his research was involved with bedrock geology mapping polymetamorphosed and polydeformed rocks (under the aegis of the U.S. Geological Survey). His research in the last 10 years has been in the area of low temperature/low pressure aqueous geochemistry.

Charles T. Hess is an Associate Professor of Physics at the University of Maine, Orono. He has been working in the field of Environmental Radioactivity for nine years, and doing radon in water measurements for eight years. He has been involved as the principal investigator in 15 grants or contracts for the U.S.E.P.A. from the Office of Water Research, from Sea Grant, and from the National Science Foundation. He has just returned from a sabbatical year at the University of Texas, School of Public Health in Houston, Texas, studying radon in water measurements, with Prof. Thomas Gesell.

John S. Williams has a B.A. in Zoology, University of Maine at Orono, 1977, and an M.S. in Geological Sciences, University of Maine at Orono, 1980. Title of thesis: Relative Contribution of Local and Regional Atmospheric Pollutants to Lake Sediments in Northern New England. He is presently employed as geochemical technician at the University of Rhode Island, studying atmospheric chemistry worldwide.

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September 26, 1983

The Honorable Don Fuqua, Chairman
Subcommittee on Energy Development
  and Applications
Science and Technology Committee
U.S. House of Representatives
B374 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman Fuqua:

Although we did not testify at the hearing on indoor air quality, The American Institute of Architects (AIA) would like to submit written comments to be included in the August 2 and 3 hearing record.

On behalf of the AIA, I would like to express our appreciation to you for holding a hearing on indoor air quality and related research. Indoor air quality is of concern to our members because of its implications for energy efficiency and the health and productivity of building occupants. Given the complexity of the indoor air quality problem, the federal government should continue to play a significant role in this research. Future study should more effectively address the extent and nature of the problem in existing residential and nonresidential buildings than has been the case in the past. And, to be of more benefit to the design community, the AIA would like the results of the research to be more widely disseminated.

Thank you for the opportunity to present our position.

Sincerely,

Robert Broshar

Robert Broshar, FAIA
President

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INDOOR AIR QUALITY--A GROWING CONCERN OF ARCHITECTS

Introduction

The incidence of worker illnesses in buildings, such as those found in the Gregory Bateson State Office Building in California, has heightened the architectural profession's awareness of the indoor air quality problem. The design profession is concerned about this issue because it affects the health and safety of people who occupy buildings. Architects and other design professionals want to be able to design buildings that are both energy-conserving and have acceptable levels of air quality as well as to detect and find solutions for existing buildings where indoor air quality is affecting the health of occupants.

Key Issues

Indoor air quality involves a complex set of issues that depend on the purpose for which a building is used, occupant activities and the construction materials utilized. Some progress has been made. For example, the major factors that contribute to indoor air pollution have now been identified. These include:

1. Improper maintenance of building lights;
2. Reductions in specified ventilation rates;
3. Inadequate ventilation systems when contaminating materials and products are used;
4. Improper balancing of air handling systems;
5. Failure to have an initial ventilation period in new buildings prior to occupancy, or periodic flushing of existing buildings;
6. Inadequate isolation and ventilation of noxious activities carried out in a building;
7. Inadequate consideration of microclimatic effects and outside levels of pollution.

The ability to detect indoor air pollutants has increased. Instruments are now available that can monitor contaminants such as carbon monoxide, dust and radon. However, there is much more to be learned. Unfortunately, progress may be inhibited by poorly-focused research efforts or an unwillingness to deal with the implications of this health issue.

Current Research Activities

The responsibility for indoor air quality research is spread over several federal agencies. Currently, the U.S. Department of Energy (DOE) deals primarily with residential buildings and the relationship between energy conservation and indoor air quality. The National Institute of Occupational Safety and Health (NIOSH) investigates incidences of worker-related illnesses in occupational settings. The Environmental Protection Agency (EPA) provides a coordinating function and other supporting research. Of these agencies, only DOE understands institutionally that there is a relationship between energy conservation and indoor air quality. However, DOE has focused little attention on nonresidential buildings.

DOE, the only agency with the ability to deal with all aspects of this complex issue, has requested no funding in FY 83 or FY 84 for its indoor air quality research programs. This reflects a lack of clear understanding of the relationship between indoor air quality and differences in building types and uses.

In most areas of building research, including energy, the federal government tends to overlook the differences between the design and construction of residential and nonresidential buildings. Residential buildings are generally smaller than nonresidential buildings and have less complex heating, ventilating and air conditioning (HVAC) systems. Just as we learned that energy solutions are shaped by the building's type and intended use, we believe that building type needs to be an important variable for indoor air quality research. We believe that DOE should strongly consider this factor when it plans its future research activities. DOE's tendency to focus on indoor air quality in residential buildings has left the design community and policymakers with an inadequate understanding of the nature and extent of indoor air quality issues in occupational and other nonresidential settings.

The federal efforts in the area of indoor air quality sidestep two important issues: energy conservation and worker productivity.

DOE has implied that indoor air quality and energy efficiency may be somewhat of an "either-or" issue. However, it is really the lack of research on cost-effective mitigation equipment and other devices that frames the issue in this manner. To suggest that improvements to indoor air quality require increasing the amount of natural ventilation belies the reality that indoor air pollution can result from, or be exacerbated by, sources outside the building, such as construction sites or vehicle repair and parking facilities. Greater air movement within a building can increase the outgassing of some pollutants. Building materials, occupant activities and equipment are all sources of pollution. Energy efficiency per se is not necessarily a cause of indoor air pollution.

Reluctance to address the indoor air quality problem also sidesteps the effect on worker productivity. In its 200 investigations of air quality problems in occupational settings, NIOSH found that the health of workers could be severely affected by indoor air quality problems. In many of these cases, NIOSH found workers with a wide variety of symptoms, including headaches, eye, nose and throat irritations, fatigue and nausea. In some cases, the reactions were severe enough to result in lost work time, reassignment and even termination.

Research Needs

Right now, there is no rigorous documentation on the extent of indoor air quality problems. Much of the existing information is anecdotal in nature. This has hampered efforts to understand the nature of the problem. To enhance the understanding of this issue, several steps need to be taken.

First, it should be ascertained whether levels of indoor air pollutants are higher in residential buildings than in nonresidential buildings. This can be determined by developing an extensive data base on air quality conditions in actual buildings and would involve sampling actual air quality conditions and collecting data on ventilation rates, equipment types and other pertinent building characteristics in a wide variety of building types and in a sufficient number of geographic locations. The data needs to be collected in a scientific and systematic manner so that results may be used with confidence by policymakers, researchers and the building community. The data collection procedure also needs to assure building owners and other key parties of confidentiality.

Second, there is a need better to understand the relationship between ventilation rates and indoor air quality conditions. Right now, there is a tendency for some practitioners to reduce ventilation rates in order to reduce a building's energy consumption. This is being done without understanding how much the ventilation rates can be reduced before indoor air quality symptoms develop. An assessment of existing building codes and standards that govern ventilation rates should be undertaken. The results would give the design community and building code officials better information for selecting equipment and ventilation strategies.

Third, additional attention needs to be given to the development of flexible mechanical systems that can accommodate functional changes in building use. The advent of open offices has brought about more frequent changes in the internal configurations of buildings. Frequently, mechanical systems are unable to keep pace with changes in configurations and the types of pollutants introduced by people, materials and equipment. Thus, pockets of pollution can develop within a building that exceed the capability of the existing HVAC system. Given the trend for more rehabilitation of existing buildings, more attention needs to be given to the development of systems that will accommodate the needs of such buildings.

Research Objectives

A comprehensive research effort is needed to provide a thorough understanding of the factors that affect indoor air quality. Major elements of such an effort should include:

- Data Base Development. A data base of indoor air quality measurements should be assembled and maintained. Building parameters and system parameters associated with the air quality measuresments should be incorporated to aid systems analysis and subsystem development.

- Institutional Issues Assessment. The effect of agency and organizational actions on indoor air quality should be identified. Key topical investigations should address the impact of codes and standards, health and safety factors as well as liability and insurance issues.

- System Definition and Analysis. A system definition and analysis effort should characterize the indoor air quality problem, identify parameter sensitivities and identify promising candidate solutions.

- Subsystem Development. A subsystem development effort should establish performance criteria and develop construction requirements.

Such a research effort is only a beginning but an important beginning. There is clearly a need for a federal role in the examination of indoor air quality.

○